JOURNAL

OF THE

AMERICAN WATER WORKS ASSOCIATION

VOL. 27 SEPTEMBER, 1935 No. 9

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Vol. 27 SEPTEMBER, 1935 No. 9

DETERMINING THE BACTERIOLOGICAL QUALITY OF DRINKING WATER

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Although it has long been known that pathogenic bacteria in water have been the causative agents in innumerable epidemics of intestinal diseases such as typhoid fever, cholera and dysentery, there is as yet no satisfactory procedure available to the average laboratory for determining promptly and definitely the freedom of any water supply from these pathogens. However, because of their natural habitat, intestinal pathogenic bacteria are never found in nature, except in combination with other classes of bacteria that abound in the normal feces of man and warm blooded animals. Of these, Bact. coli are always present in enormous numbers and Bact. aerogenes to a lesser extent. Although it is definitely proven that bacteria of this latter group also occur on certain vegetation and in virgin soil, nevertheless, these two genera have very many characteristics in common. For these reasons they usually have been grouped together and first were designated as the B. coli group and later the coli-aerogenes group. Thus it is that although bacteria of the coli-aerogenes group, insofar as we know, do not cause disease and are not a factor in our well being, their presence in a water, because of their origin, has been recognized as an indicator that such water is polluted with sewage or

surface drainage, or both, and hence may also contain intestinal pathogens. Furthermore, the concentration of coli-aerogenes group organisms in water has been considered as a measure of the extent of the pollution which has occurred.

It is upon this basis of coli-aerogenes density that accepted bacteriological standards for the safety of water for drinking and culinary purposes rests. The bacteriological section of the U. S. Treasury Department standard is of this nature and includes both sections of the coli-aerogenes group determined under definite specified procedures. Recently much has been written about the elimination of the aerogenes group from consideration in this connection on the assumption that this genus if present in the water may have originated from sources other than the human body. Restrictive media, differentiation procedures and various other devices have been suggested for selective development of the Bact. coli section and suppression of the aerogenes section of the bacteria composing the coli-aerogenes group in water. It need only be remarked that any narrowing of this group by any of these methods, regardless of their accuracy or practicability, has the ultimate, practical effect of lowering the established limiting standard, that is, of increasing the permissible density of coli-aerogenes organisms. Therefore, if such analytical procedures are practiced, this standard limit should be tightened accordingly if we are to retain our present degree of purity of drinking water supplies.

The present accepted procedure for determining the presence and density of organisms of the coli-aerogenes group in water is the dilution method using a liquid media. For the examination of drinking waters to determine their conformity to the Treasury Department standard, five 10 cc. portions of the sample are inoculated into tubes of standard broth and the cultures producing gas further confirmed for definite characteristics of the group. The limit of organisms permitted under this determination is 1.05 per 100 cc. of water. Inasmuch as the five 10 cc. tubes thus inoculated will measure not less than 2.2 organisms per cc., the method is too coarse for ascertaining accurately the coli density within the desired range. This deficiency can be overcome, in part at least, as has been pointed out before (1), by examining larger size portions of sample, say 50 cc. or 100 cc.

This point is clearly illustrated by the results, kindly furnished through the courtesy of Harry E. Jordan of the Indianapolis water

plant for the year 1934, where both five 100 cc. and five 10 cc. portions of the finished water are examined. During the entire year, out of 365 daily samples, on only two days did the 10 cc. portions indicate the presence of members of the coli-aerogenes group, while nineteen 100 cc. portions were positive. Moreover, in one month during seven different days, a total of nine 100 cc. portions were positive indicating that some abnormal circumstance was permitting a slight, yet discernible deterioration of the high bacteriological quality, but which was altogether undetectable by the 10 cc. portion analyses.

Again, our examination of Cincinnati tap samples over a period of about a month disclosed a total of twenty-one 100 cc. portions out of 165 positive for coli-aerogenes, whereas during the same period only five 10 cc. portions were confirmed. The results in this case also showed a continued day to day appearance of positive 100 cc. tubes indicating the approach of higher bacterial numbers not so clearly disclosed by the results from the 10 cc. portions examined, although the bacterial density was evidently frequently sufficient to be reflected in the 10 cc. portions of the samples.

INTERPRETATION OF ANALYTICAL RESULTS

The Phelps' index or reciprocal method of interpretation of the analytical result from the liquid media determination as given in the present Standard Methods does not apply to the case of a multiple number of tube results at only one dilution or in fact to more than one tube in each of a series of dilutions. Even in the single tube dilution series for which it was designed, the principal is not mathematically sound. Moreover, the present edition of Standard Methods contains no suggestion for the interpretation of multiple tube analyses. There is definite need, therefore, when the multiple tube procedure is employed, as it now generally is, for some uniform method of properly interpreting such analytical results and of expressing them in comparable terms of bacterial density per unit volume of sample, regardless of the number and size of portions planted at one or more dilutions. The most generally accepted procedure for this purpose is that of the most probable number (M.P.N.). The M.P.N. in simple language is nothing more than that bacterial density, which, if it had been actually present in the sample under examination, would, more frequently than any other, have given the observed analytical result.

The theory and method of computation of the M.P.N. has been developed by various writers over a considerable period of years in

this country and abroad. Simplification of the somewhat involved mathematical treatment has been suggested by one of us (2) and tables of M.P.N. values corresponding to the combinations of portions of sample most commonly planted in routine analytical work have been made available (3, 4, 1).

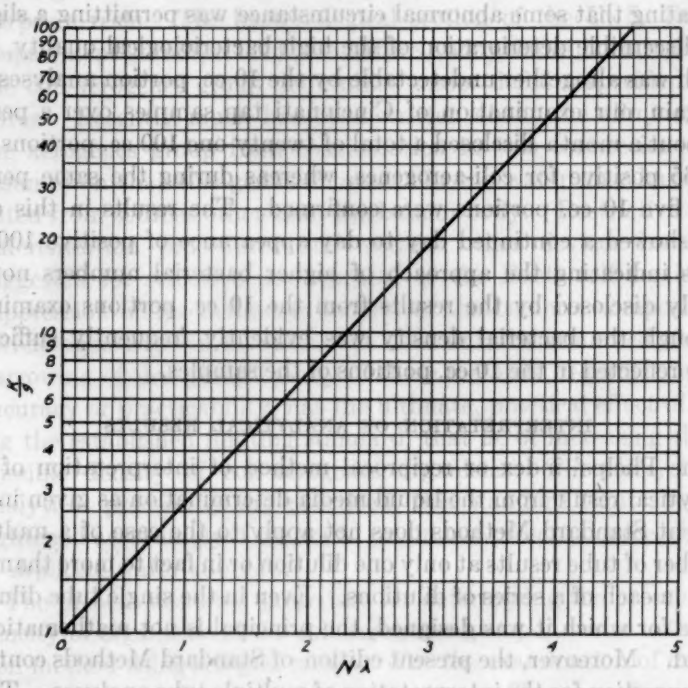

FIG. 1. RELATION BETWEEN M.P.N. AND ANALYTICAL RESULT WHEN ANY NUMBER OF EQUAL PORTIONS OF SAMPLE ARE EXAMINED

$N\lambda = 2.3026 \log \frac{K}{q}$. λ = M.P.N. per cc. of sample. N = size in cc. of portion examined. K = number of equal portions examined of size N. q = number of portions showing no growth.

Where only equal portions, at a single dilution are planted, the result may be interpreted in terms of the M.P.N. value, as Greenwood and Yule (5) state, by the formula:

$$N\lambda = 2.302585 \log \frac{K}{q}$$

Where N = size in cc. of the portion examined,
K = number of portions of size N,
q = number of portions showing no growth,
λ = M.P.N. per cc. of sample.

This expression can readily be plotted in the form of a curve, figure 1, from which may be read direct the M.P.N. corresponding to any observed analytical result where any number of tubes have been inoculated with the same size portion of the sample.

M.P.N. values corresponding to results from more than one size portion are more easily obtained from tabulated computations of such values as mentioned above or, if necessary, by computation direct. However, an approximate value for such a series of dilutions may be obtained by employing the above formula or the chart, using for the purpose the results from the middle dilution of the series.

The optimum size of inoculum

It is always advisable in planting portions of a sample in nutrient media tubes to select that size of portion which will give a determinative result, that is, one in which not all tubes show no growth or all show growth. The optimum size portion obviously would be such that equal numbers of tubes show growth and no growth, or, expressed in another way, in an extensive series of multiple tube tests of the same size portion of sample the smallest possible percentage of tests should be indeterminate. In other words the sum of these all positive and all negative tests should be a minimum.

An examination of the expansion of the binomial giving the frequencies of occurrence of the different results which will be obtained in the analysis of the sample, discloses that the optimum size of portion to be planted, when equal portions are employed, is given by the expression

$$e^{-N\lambda} = 0.5 = e^{-0.693}$$

or

$$N\lambda = 0.693 \quad \text{or} \quad N = \frac{0.693}{\lambda} \qquad (1)$$

where N = size of portion in cc.
λ = M.P.N. per cc.

Hence, if the approximate bacterial content (λ) of the sample to be examined can be estimated, the size of portion to plant (N) can be readily obtained from this relationship or by interpolation from figure 2 which is a graph of this equation (1). This same procedure or chart may be used to ascertain the optimum size of the middle

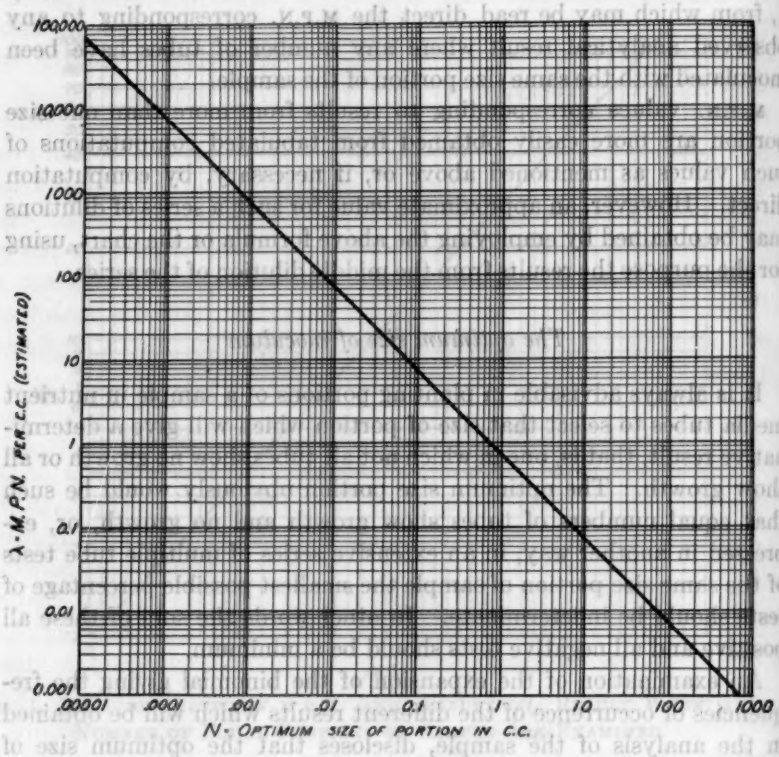

FIG. 2. RELATION BETWEEN M.P.N. AND OPTIMUM SIZE FOR PORTIONS OF EQUAL SIZE OF SAMPLE TO BE EXAMINED

$N = \frac{0.693}{\lambda}$. N = size in cc. of portion to be examined. λ = M.P.N. per cc.

portion when different sized portions in geometrical or other series are to be planted.

In any extensive series of multiple tube tests in which the same size portion of sample is employed, the chances are that a definite percentage of the tests will produce all positive or all negative results, the exact number being a function of the concentration of coli-aero-

genes organisms, and size and number of portions examined. All such results are, of course, indeterminate for the M.P.N. value. In general, when equal portions of the sample are planted, the largest percentage of such series that will give a determinate result (some positive and some negative tubes) is given by the relationship:

$$P = 100\,[1 - (e^{-N\lambda})^K - (1 - e^{-N\lambda})^K] \qquad (2)$$

when P = the percentage of samples that will give a determinate result,

N = size in cc. of portion of sample examined,

λ = M.P.N. per cc.

K = number of portions of size N in each test.

If now the optimum size portion N as determined in (1) is used, then $e^{-N\lambda} = 0.5$ and substituting this value in (2)

$$P = 100\,[1 - 2(.5)^K] \qquad (3)$$

Employing these formulae, it is possible to compute the percentage of determinate results that will be obtained in any large series of tests when any number of tubes are used in each test. Computed values of P are presented in table 1 when the optimum portion of sample is planted in any number of tubes from 2 to 10 and also when 1, 10, or 100 cc. portions are planted of a sample containing 1.05 coli-aerogenes group organisms per 100 cc. (the Treasury Department limit).

An inspection of these data shows, for example, that when only two equal portions of the optimum size are planted, 50 percent of such series will be either both positive or both negative and hence, not determinative for the M.P.N. value, whereas if 5 such equal portions are planted, 93.75 percent of the results will be determinative. These data also show clearly the desirability of planting larger portions than 10 cc. amounts when waters approximating in coli-aerogenes content the Treasury Standard for drinking waters are under examination. For example, when five 10 cc. portions of such a water are planted in broth tubes, only 40.8 percent of such tests would be expected to be determinative (that is 59.2 percent would either all show growth or all show no growth), whereas if five 100 cc. portions of the same water were used, 87.9 percent would be determinative (some positive and some negative growth).

For a discussion of the accuracy of the computed M.P.N. result, the reader is referred to discussions of other writers such as Green-

wood and Yule (5), Reed (6), Halvorson and Ziegler (7), Allen (8), etc. In general, it may be said that the probable error is large (as much as 150 percent of the M.P.N.) when a moderate number, say 5 or 10 tubes, is examined. This error is least, however, when from 70 to 80 percent of the total tubes in a test show growth, depending upon the number of tubes used. Obviously, therefore, in selecting the size of portion to examine as determined by (1) above it would be advisable, for the sake of higher accuracy of the result, to select a size of N somewhat larger than the computed value, rather than somewhat smaller, in order that there may result more positive tubes than

TABLE 1

Percentage of determinative results to be expected, P, when a definite number of portions, K, of a sample are planted

NUMBER OF EQUAL SIZE PORTIONS PLANTED = K	$N\lambda$ (= SIZE OF PORTION IN CC. × CONCENTRATION PER CC.)			
	0.693 (= optimum)	$N = 1$ $\lambda = 0.0105$	$N = 10$ $\lambda = 0.0105$	$N = 100$ $\lambda = 0.0105$
2	50	2.1	19.9	45.5
3	75	3.1	27.0	68.1
4	87.50	4.1	34.3	80.6
5	93.75	5.1	40.8	87.9
6	97.88	6.1	46.7	92.3
7	98.44	7.1	52.1	95.0
8	99.22	8.1	56.8	96.8
9	99.61	9.0	61.1	97.9
10	99.80	10.0	65.0	98.6

negative ones. In any event it seems reasonable to conclude that the dilution tube method cannot result in an accurate enumeration of coli-aerogenes organisms and that, therefore, the need for an acceptable and dependable method still remains.

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DISCUSSION

R. E. NOBLE (*Department of Health, Chicago, Ill.*): If this conclusion is based on pure culture considerations, as it doubtless is, then the inherent inaccuracy of measurement shown by these careful workers becomes magnified when raw waters are tested. Raw waters contain other organisms which often hinder coli-aerogenes growth or sometimes suppress it completely. In this light, the need for an acceptable and dependable method of coli-aerogenes enumeration seems urgent.

There are those who feel that a promising way out of this difficulty lies in the realm of direct plating media. This avenue of approach offers such real advantages over the liquid dilution method as to warrant thorough investigation of its possibilities. But relatively little work has been done along this line compared to that done on liquid media. If correspondingly as much study were devoted to the direct plating phase of coli-aerogenes enumeration; toward the development of a suitable and adequate direct plating medium and to the physics of its application, it is quite reasonable to believe that this effort would yield a method superior to the present one. A single laboratory or two cannot do all the work required to accomplish this objective. Many workers must contribute to such investigation. Coördinated work, of course, would bring out the merits of this possible solution to the present problem faster.

LIMITING STANDARDS OF BACTERIAL QUALITY FOR SOURCES OF PURIFIED WATER SUPPLIES

By H. W. Streeter

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The growing difficulties experienced in obtaining purified water supplies of safe and palatable quality from sources highly polluted by sewage and industrial wastes have made apparent the need of applying some rational standard whereby excessive pollution of these sources can be brought under some definite and economical control. In several states, a tentative standard of this kind has been adopted, based on the results of a comprehensive study of the limitations of current water purification processes made a few years ago by the U. S. Public Health Service in connection with its investigations of stream pollution. Although the results of this study have been fully published elsewhere, it has seemed desirable to undertake in this paper an interpretation of them with particular reference to the formulation of a working standard such as above indicated and to illustrate its application in one or two specific cases.

In connection with the Public Health Service's study, three major series of observations were made. The first consisted of a detailed collective survey of the performance of 17 representative municipal water purification plants located on the Ohio and several other rivers; the second, of a similar survey of 14 plants located along the Great Lakes; and the third, of a long series of observations, aggregating some five years in time, at a large-scale experimental water filtration plant located on the Ohio River at Cincinnati. Although the combined data of this study embraced almost every conceivable combination of water treatment, ranging from simple chlorination to highly elaborated filtration, with double-stage coagulation, sedimentation and chlorination, the process most frequently observed was ordinary rapid-sand filtration, aided by post-chlorination. As this particular combination of treatment appears to represent the normal type used most widely throughout the United States, its performance represents probably the most reasonable basis of any general requirements which might be adopted for limiting raw water pollution.

From combined data obtained from the purification of raw waters taken from the Great Lakes and the Ohio River, two curves designated as "A" and "B" respectively, have been drawn in figure 1, showing the average relationship observed in each case between the numbers of B. coli in the raw water and the corresponding numbers in the final chlorinated effluent. The middle curve "C" has been drawn to show the average trend of curves "A" and "B." The intersections of these three curves with the horizontal line drawn through the ordi-

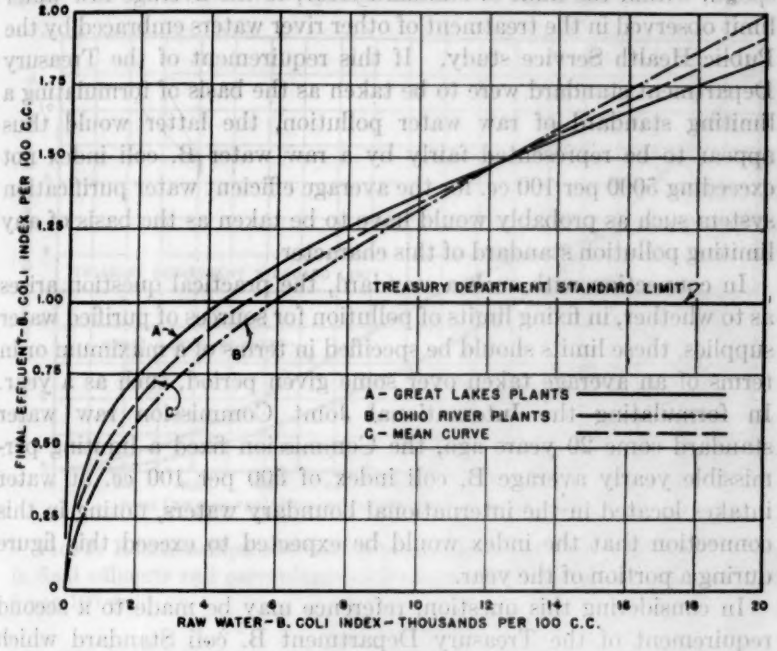

FIG. 1. Relationships observed between number of B. coli in raw waters and corresponding numbers in final effluents.

nate representing a B. coli index of 1.0 per 100 cc. indicate the limiting numbers of raw water B. coli yielding effluents meeting the primary requirement of the Treasury Department B. coli standard; that is, having an average B. coli index not exceeding 1.0 per 100 cc. For Great Lakes waters this limit is shown to be slightly over 4000 and for Ohio River 6000, the corresponding mean given by curve "C" being about 5000, all in terms of B. coli per 100 cc.

As the divergence between curves "A" and "B" is so small as to

lie within their respective deviations due to standard observational error, the limiting raw water B. coli index of 5000 per 100 cc. indicated by the mean curve "C" may be considered as fairly representing the maximum degree of raw water pollution which the average efficient Ohio River or Great Lakes filtration plant could purify to an extent such as to meet the primary requirement of the Treasury Department drinking water standard with respect to average B. coli content. This maximum, it may be added, has been found to correspond, within the limit of standard error, to the average raw water limit observed in the treatment of other river waters embraced by the Public Health Service study. If this requirement of the Treasury Department standard were to be taken as the basis of formulating a limiting standard of raw water pollution, the latter would thus appear to be represented fairly by a raw water B. coli index not exceeding 5000 per 100 cc. for the average efficient water purification system such as probably would have to be taken as the basis of any limiting pollution standard of this character.

In connection with such a standard, the practical question arises as to whether, in fixing limits of pollution for sources of purified water supplies, these limits should be specified in terms of a maximum or in terms of an average taken over some given period, such as a year. In formulating the International Joint Commission raw water standard some 20 years ago, the Commission fixed a limiting permissible yearly average B. coli index of 500 per 100 cc. at water intakes located in the international boundary waters, noting in this connection that the index would be expected to exceed this figure during a portion of the year.

In considering this question, reference may be made to a second requirement of the Treasury Department B. coli Standard which specifies in effect that during a given period of time (not stated in the Standard) not more than 5 percent of the individual samples of a given water should show a B. coli index exceeding 6.0 per 100 cc. This requirement was inserted in order to allow some degree of variation in the B. coli content of a water at different times, but to limit this variation within reasonable bounds.

In some waters, it has been found that where they conform to the first requirement of the Treasury Department standard (i.e. show an average B. coli index not exceeding 1.0 per 100 cc.) they also tend to meet the second requirement as well. In such cases a maximum of 5000 B. coli per 100 cc. could be taken as an average limit of raw

water pollution with the expectation of producing effluents meeting both requirements of the Treasury Department Standard.

In other waters, however, this consistency with respect to meeting both requirements of the Treasury Department Standard may fail to be realized. In such cases the limiting permissible average numbers of raw water B. coli would have to be scaled down to a point such that the frequency with which the B. coli index of the effluent exceeded 6.0 per 100 cc. would not be greater than 5 percent, as provided in the second requirement of the Standard.

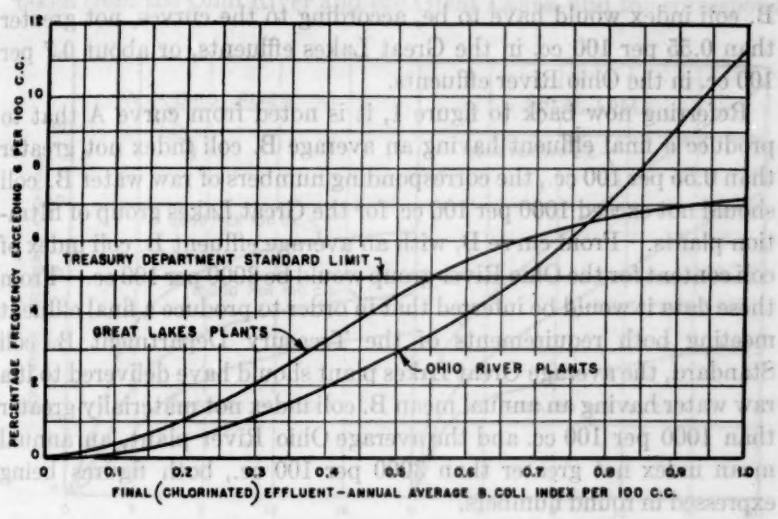

FIG. 2. Relationships observed between annual average numbers of B. coli in final effluents and percentages of frequency with which numbers exceeded 6 per 100 cc.

In order to illustrate the method by which the proper limiting raw water average could be determined in such an instance, reference may be made first to figure 2, in which two examples of non-conformance in the above respect are afforded by actual data collected by the Public Health Service from the two groups of municipal filtration plants observed, respectively, on the Ohio River and along the Great Lakes.

In this chart, a curve has been drawn for each one of these two groups of plants, showing the relation observed between the yearly mean B. coli index of the several effluents in each group and the percentages of frequency with which an index of 6 per 100 cc. was

exceeded in these effluents. In order to provide an enlarged ordinate scale, only a portion of each curve has been shown, extending up to an average B. coli index of 1.0 per 100 cc.

On referring to figure 2, it will be noted that when the annual average B. coli index of each group of effluents was as high as 1.0 per 100 cc., the limit fixed by the first requirement of the Standard, the observed frequency with which an index of 6.0 occurred was greater than 5 percent, the limit fixed by the second requirement of the Standard. In order to meet this second requirement, the average B. coli index would have to be, according to the curves, not greater than 0.55 per 100 cc. in the Great Lakes effluents, or about 0.7 per 100 cc. in the Ohio River effluents.

Referring now back to figure 1, it is noted from curve A that to produce a final effluent having an average B. coli index not greater than 0.55 per 100 cc., the corresponding numbers of raw water B. coli should not exceed 1000 per 100 cc. for the Great Lakes group of filtration plants. From curve B, with an average effluent B. coli index of coli content for the Ohio River group would be 3000 per 100 cc. From these data it would be inferred that in order to produce a final effluent meeting both requirements of the Treasury Department B. coli Standard, the average Great Lakes plant should have delivered to it a raw water having an annual mean B. coli index not materially greater than 1000 per 100 cc. and the average Ohio River plant, an annual mean index not greater than 3000 per 100 cc., both figures being expressed in round numbers.

In order to check the general rationality of these limiting averages, let us consider the problem from another viewpoint. If the relationships shown by the curves in figure 1 are reasonably valid, then a study of the frequencies with which the B. coli index of the two groups of raw waters under discussion exceeded an amount clearly indicating an overburdening of the average efficient filtration plant during comparatively short periods of time should afford an indication of temporary lapses in the quality of effluent roughly corresponding to failure to meet the second requirement of the Treasury Department B. coli Standard.

The results of an extended series of observations by the Public Health Service at its Cincinnati experimental plant have indicated that the upper limit of raw water pollution with which the average filtration plant, when reinforced by prechlorination, can produce a final effluent meeting the first requirement of the Treasury Depart-

ment B. coli Standard is measured approximately by a B. coli index of 20,000 per 100 cc. If a given filtration plant were thus reinforced temporarily by prechlorination, or by any other equally effective supplementary treatment, during periods in which the numbers of raw water B. coli exceeded 5000 but not 20,000, it might then be expected to produce an effluent meeting the Treasury Department Standard except during periods in which 20,000 were exceeded.

In figure 3 two series of curves are given showing the relationships between the yearly average numbers of B. coli observed in raw waters taken from the Ohio River and the Great Lakes, and the correspond-

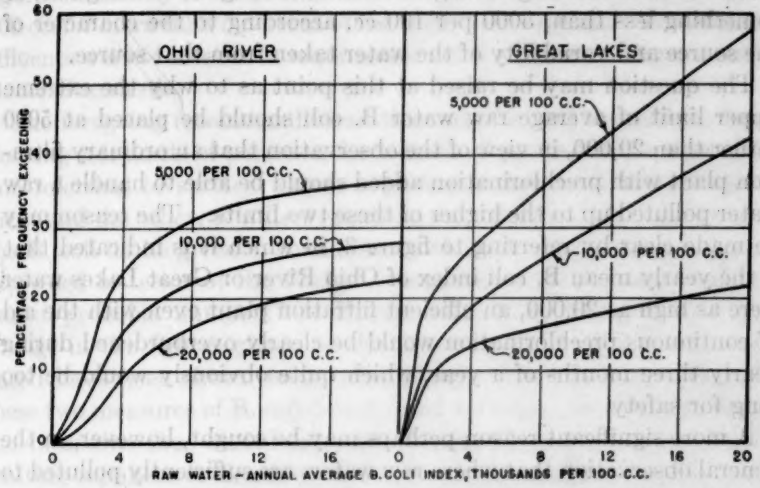

FIG. 3. Relationships observed between annual average numbers of B. coli in raw waters and percentages of frequency with which numbers exceeded 5,000, 10,000 and 20,000 per 100 cc.

ing percentages of frequency with which these numbers exceeded 5,000, 10,000 and 20,000 per 100 cc. respectively. On referring to these curves, it is noted that the number exceeded 20,000 for 5 percent of the time when the yearly average B. coli content approximated 3000 in the Ohio River and 1000 in the Great Lakes. If this criterion were applied, the limiting yearly average number of B. coli permissible in each of these two sources of raw water supply would thus be the same as would be indicated by a study of the curves given in figures 1 and 2.

From the foregoing analysis of these two cases, based on actual

data, it may be inferred that if a limiting B. coli standard for sources of purified water supplies in general were to be formulated from these data on the basis of the production of effluents meeting both requirements of the Treasury Department B. coli Standard, it should contain the following basic requirements:

(1) That the average B. coli index of the raw water as delivered for treatment, when considered over a significantly long period of time, such as a year, should in no case exceed 5000 per 100 cc., and

(2) That the B. coli index of such a water should not exceed 20,000 per 100 cc. during more than 5 per cent of the period considered, in which case the limiting average B. coli index might be as high as, or something less than, 5000 per 100 cc. according to the character of the source and variability of the water taken from that source.

The question may be raised at this point as to why the extreme upper limit of average raw water B. coli should be placed at 5000 rather than 20,000, in view of the observation that an ordinary filtration plant with prechlorination added should be able to handle a raw water polluted up to the higher of these two limits. The reason may be made clear by referring to figure 3, in which it is indicated that if the yearly mean B. coli index of Ohio River or Great Lakes water were as high as 20,000, an efficient filtration plant even with the aid of continuous prechlorination would be clearly overburdened during nearly three months of a year, which quite obviously would be too long for safety.

A more significant reason perhaps may be sought, however, in the general observation that where raw waters are sufficiently polluted to show a yearly mean B. coli index exceeding 5000 or thereabouts, difficulties have been experienced in the effective purification of such waters quite aside from the production of effluents consistently meeting an acceptable standard of bacterial quality. Examples may be cited in certain sections of the Ohio River, notably at East Liverpool, Steubenville and between Huntington and Portsmouth; in the lower end of Lake Michigan, notably at Whiting and East Chicago; in the lower Delaware River at Philadelphia and Chester; in the Hudson River at Albany, and in the Mahoning River at Youngstown, where the annual average B. coli index ordinarily ranges upwards from 5000 to 20,000 or more and the troubles experienced in producing consistently safe and palatable water supplies, even with the most highly elaborated processes of water purification have in some instances forced the abandonment of the original sources

of supply in favor of less polluted ones and in others would undoubtedly do so if any alternative sources were at hand.

In some parts of the country, where underground or stored surface waters of good physical quality and low degree of pollution are available, filtration may not be required except where pollution is excessive and the only necessary form of purification may be simple chlorination. For waters of this class treated by chlorination alone, the limiting safe average degree of pollution, as indicated by the combined results of the Public Health Service observations, would be represented by a mean B. coli index approximating 50 per 100 cc., or a figure sufficiently lower so that the number would not exceed 400 per 100 cc. for more than 5 percent of the time, assuming that the treated effluents were to meet both requirements of the Treasury Department B. coli Standard.

The foregoing recommendations thus may be said to embrace two limiting standards of pollution for sources of purified water supplies, one referring to surface waters requiring complete filtration treatment and the other, to waters requiring only chlorination. Although the B. coli limits given in connection with these standards have been expressed in terms of the Phelps' index, they could be expressed in "most probable numbers" of B. coli with little if any significant change in the figures given, as the relationships on which they are based have been shown to be substantially the same whichever of these two measures of B. coli density may be used. In a broad sense, the measures thus stated may be considered as indicating actual limiting numbers or densities of B. coli, such as might be obtained from direct plate counts, if enumerations of this group by direct plating methods were possible.

As bacteria of the B. coli group remain the most signficant indices of water pollution affecting the hygienic quality of water supplies, the present paper has been confined to a discussion of working standards based on the enumeration of this group, as affording perhaps the most simple and direct means to this end. Recent experience has suggested, however, that an adequately comprehensive statement of a complete standard for sources of purified water supplies should also include requirements for minimizing or excluding certain chemical substances, such as phenols, fluorides, cyanides, etc., which are not readily and completely removed by ordinary purification methods and may render treated waters either grossly unpalatable or actually harmful to domestic consumers. This phase of the subject may well be left, however, for further studies to determine more precisely the

safe limits of these substances in waters intended for human consumption, meanwhile excluding them from all sources of such waters where possible. For the present, reasonably simple bacterial standards, such as have been described in this paper, would appear to offer the most immediate practical solution of the general problem.

SUMMARY AND CONCLUSIONS

Extensive studies by the U. S. Public Health Service of the efficiency and limitations of current processes of water purification used throughout a large section of the United States have established the safely permissible limits of raw water pollution which are consistent with the production of effluents meeting given standards of bacterial quality. In order to deliver effluents conforming to the first requirement of the U. S. Treasury Department B. coli Standard, these raw water limits, expressed in terms of B. coli numbers, have been found to be as follows for the average water purification system of the type and degree of elaboration indicated:

	B. coli per 100 cc.
1. Simple chlorination	50
2. Rapid-sand filtration, with postchlorination	5,000
3. Rapid-sand filtration, with pre- and postchlorination combined	20,000

On the basis of these maxima, it is shown, by the analysis of data obtained from two groups of filtration plants treating raw waters taken from the Ohio River and the Great Lakes, respectively, that in order to produce effluents meeting both requirements of the present Treasury Department B. coli Standard, the yearly average B. coli content of Ohio River water should not exceed 3000 per 100 cc., and that of Great Lakes water, 1000 per 100 cc.

From a consideration of these data, the following general statement may be made of two limiting standards of quality for sources of purified water supplies, the first being applicable to waters requiring filtration treatment and the second, for waters requiring only simple chlorination.

A. For waters requiring filtration

1. The average B. coli index of the raw water as delivered for treatment, when considered over a significantly long period of time, such as a year, should in no case exceed 5000 per 100 cc., and

2. The B. coli index of such a water should not exceed 20,000 per 100 cc. during more than 5 percent of the period considered, in which

case the limiting B. coli index might be as high as, or something less than 5000 per 100 cc. according to the character of the source and the variability of the water taken from that source.

B. For waters requiring only simple chlorination

The average B. coli index of the raw water, when considered over a similarly long period of time, should not exceed 50 per 100 cc., or a figure sufficiently lower so that the number would not exceed 400 per 100 cc. for more than 5 percent of the time.

For all practical purposes, the term "index" as used above may be expressed either in terms of the Phelps number or in terms of the "most probable number" as comparative studies have indicated that the relationships on which the limiting figures given have been based are substantially the same whichever of these two measures of B. coli density may be used. In a broad sense, the limits given may be considered as indicating actual densities of B. coli organisms, whatever may be the method of their determination.

As the foregoing standards have been formulated with a particular view to the production of effluents meeting the present Treasury Department B. coli Standard, the definition of the B. coli group of bacteria followed in this connection would be more strictly the same as in the latter Standard, which specifies that organisms of this group shall conform to those demonstrated by the "completed test," as described in the 1923 edition of the "Standard Methods" of the American Public Health Association. In general, however, it is the writer's opinion that for raw or untreated waters, this definition might well be broadened, to include bacteria of the "coli-aerogenes" group, in view of the present trend of thought concerning the primary sanitary significance of this wider group as an index of water polution.

Although recent experience would suggest that an adequately comprehensive statement of a limiting standard for sources of purified water supplies should include requirements for minimizing certain toxic or otherwise harmful chemical substances not readily or completely removed by ordinary processes of water purification, the present paper has been confined to a discussion of bacterial standards as affording the most direct and simple criterion for more immediate practical application. The question of limiting chemical standards may well be left for further study and determination by qualified experts in water chemistry and physiology, meanwhile excluding known substances of a harmful nature from sources of water supply where possible.

RESULTS OF ALGAL ACTIVITY, SOME FAMILIAR, OTHERS OBSCURE

By W. C. Purdy

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I. TASTES AND ODORS IN POTABLE WATER

This is an old subject, as every waterworks man knows. On the one hand stands the consumer, who simply will not accept a bad-tasting or a bad-smelling water, even if such water be demonstrated to be quite harmless. On the other hand are lined up not only the inexorable laws of nature, but also the limitations of mankind as to his disposal of industrial wastes. Between stands the waterworks man, with olive branch extended in one hand and a microscope held in the other.

The laws of nature result in the production of luxuriant crops of algae and of alga-like organisms. The chief requirement of growth, aside from water, is sunlight, so it is no wonder that small lakes and reservoirs, selected by man, or perhaps constructed by him, are immediately appropriated by these organisms as a most suitable location in which to stage an amazing and persistent growth, and and thereby hangs the all too-familiar tale of a succession of tastes or of odors, which plague the waterworks man and make him the target for abusive remarks on the part of an exacting consumer, the Public.

Proper handling of this situation requires certain measures which are preventive, as well as other measures which are corrective or remedial. The plan used some years ago was to apply copper sulphate when and if the algal growth reached such proportions as would cause taste or odor, the amount of chemical being based on the lethal dose required by the particular organisms present. This, in turn, required microscopic examination by some one familiar with these types of life. It was quickly discovered that an explosive and expensive outbreak could be prevented by applying the chemical treatment in the early stages of the growth, so regular examinations

are now arranged in order to obtain advance information of an impending algal attack.

In actual practice, copper sulphate sometimes fails. In some of these cases chlorine will do the work, and sometimes both chlorine and copper sulphate may be necessary or ammonia and chlorine. The various interrelations of the many factors concerned produce a series of complicated situations with which many of you are quite familiar.

Of late years, a most welcome ally has appeared in the form of preparations of carbon, which function as remedial agents, effecting the removal of taste and odor from the water to an extent quite impossible heretofore. Apparently the use of carbon, in addition to being satisfactorily efficient in high percentage of cases, has the additional great advantage of favorable appeal to the public—and this is no small item. Johnson,[1] of the New Castle Water Company, thinks this favorable attitude is because of the simplicity of use—the carbon absorbing the offensive taste or odor—and then this carbon itself being removed. I suspect the proposition appeals to the lay public somewhat as does the use of a handful of cotton waste to mop up some oil or grease, then throwing away the soiled waste.

II. CLOGGING OF FILTERS BY MICROSCOPIC ORGANISMS

Many organisms are offenders, depending somewhat on the season. In the Ohio River there is a "wave" of diatoms in the fall, and one of less extent in the spring, that causes trouble in those waterworks which take their raw water from this stream. The diatoms are in some respects worse offenders than the ordinary soft-bodied organisms because of the durable coating of silicon dioxide forming the outside of the diatom body. These stiff, unyielding bodies quickly and effectively clog the filter beds, and require careful washing for removal. The chief offender in the Ohio River is a long, slender, needle-like form which belongs to the Synedra group.

Inasmuch as certain streams are turbid most of the time it would seem that such streams should be relatively free of diatoms, and of other minute plants as well, because of the requirements of these plants for sunlight. Indeed, in certain of our sedimentation basins, notably at Louisville, artificial turbidity has been produced for the purpose of checking the growth of diatoms and related organisms by thus diminishing the sunlight.

[1] Taste and Odor Control with Activated Carbon. B. F. Johnson, Jour. Pennsylvania Waterworks Operators Assoc., 1932.

Against this background of the better-known matters of taste and odor, and of clogging of filters with microscopic organisms, we now wish to discuss two results of algal activity that are less widely known, but that are, meantime, of considerable practical importance. We refer to (1) the possible toxic effect of water in which certain algae are abundant, and (2) the oxygen-producing power of certain algae which, even in the absence of atmospheric aeration, may provide sufficient dissolved oxygen for a moderately polluted stream.

III. THE POSSIBLE TOXIC EFFECT OF CERTAIN ALGAE

For several years past, it has been thought possible and even probable that alga effects might not stop with a warning odor or taste, but that, under certain conditions, there might be produced substances that are dangerous or even toxic to users of the water. Very fortunately, this matter has been investigated by Fitch, assisted by Bishop, Boyd, Gortner, Rodgers and Tilden, and the results published (1934) as Paper No. 1248 Journal series, Minnesota Agricultural Experiment Station. This study lists occurrences of toxic effects dating as far back as 1878, as shown by the death of domestic animals (including sheep, hogs, chickens, cattle and horses) a few hours after drinking water which was, at the time of using, in contact with unusually large quantities of certain kinds of algae of the blue-green group.

Autopsies on a number of these animals showed no gross pathology. Laboratory animals (guinea pigs and rabbits) inoculated with macerated tissues from the dead animals showed no ill effects, and in one instance, the alga itself, fed directly to rabbits, guinea pigs and cattle seemed harmless. In another case, however, suspensions of the same alga proved fatal when fed to rabbits, guinea pigs and chickens.

The alga growth, in every one of the ten instances, recorded in this study by Fitch, et al., occurred in lakes, and these were practically all small, shallow "saucer" lakes. The toxic effect was the more marked when the wind, blowing across the lake, caused heavy concentration of the alga along the lake margin where the animals were accustomed to drink. It is also noticeable that in every case noted, the alga apparently responsible belonged to the blue-green category.

The investigators state, in effect, that the poison (1) is non-volatile, (2) can exist in the water around the algae, (3) will pass through filters such as collodion bags, (4) disappears upon putrefaction of the

algae, and (5) is not botulinus toxin. The investigators further state, in conclusion: "All tests and reactions indicate that the poison is an organic compound but it has not as yet been possible to isolate it from the mixture of inert organic compounds with which it is associated."

Positive evidence of this sort as to the actual toxic products of algae is somewhat disconcerting, particularly as we have, in the main, regarded algae as harmless, or as actually beneficial by reason of their photosynthetic activity. It is reassuring, however, to note that relatively speaking, these periods of toxic effects are few. In the paper referred to, one farmer who in 1930 suffered loss of several animals had pastured his stock for 30 years along this particular lake, and, so far as known, only once, 19 years before, had any similar trouble developed.

All these toxic effects were noted on domestic animals. Apparently these waters were not used by man and no data are available relative to the possible injurious effects in case of such use. There would seem to be a possibility, however, that should not be ignored, even though growth of blue-green algae in our reservoirs is usually confined largely to the surface waters and the intake for the service mains is, as a rule, several feet under the surface.

In this connection, it may not be out of place to refer briefly to the frequent occurrence of mild intestinal disorders among the human population which used certain water supplies that, on investigation, were found to contain very heavy growths of algae, chiefly of the blue-green group. Tisdale gives an illuminating account[2] of such conditions relative to a water supply obtained from the Elk River. To be sure, factors other than alga growth were present, and may have contributed materially to the net ill effects produced by the water. It is significant that the bacterial condition of this water meantime was quite good, conforming to the Treasury Department Standards, and that a careful study of the entire situation by Veldee[3] showed not only this fact, but the evidence also strongly suggested that the intestinal trouble experienced by users of the water was "brought about by the presence in the water of some chemical irritant whose physiological action simulated a strong purgative."

[2] Epidemic of Intestinal Disorders in Charleston, W. Va. Occurring Simultaneously with Unprecedented Water Supply Conditions. Amer. Jour. Public Health, 21: February, 1931.

[3] An Epidemiological Study of Suspected Water-borne Gastroenteritis. Amer. Jour. Public Health, 21: November, 1931.

Various other instances might be cited, such as the mild dysentery-like epidemic affecting a portion of the Washington, D. C. population while using, after prolonged drought, the remnant of water from the Anacostia River, where algae were very abundant. The effects produced were apparently identical with those observed in the West Virginia field, and in various Ohio River cities investigated by Veldee. While definite connection between these intestinal disturbances and the known abundance of algal growth meantime has not been definitely established, there is sufficient evidence to make us ponder the possibility, at least, of a causal connection such as was so clearly indicated, in the study by Fitch, between domestic animals and a water supply containing heavy growths of blue-green algae.

IV. EFFICIENCY OF MICROSCOPIC ALGAE IN PRODUCING OXYGEN IN POLLUTED WATER

To the natural stream or water body freely exposed to the air, there is an unlimited supply of atmospheric oxygen available. A shallow stream has the advantage over a stream with a deep channel. If the former be heavily polluted, absorption of atmospheric oxygen may be sufficient for all needs. Moreover, abundant sunshine penetrating the shallow depths usually produces a growth of algae which will augment, if necessary, the atmospheric oxygen.

If the deep, slow-flowing stream be heavily polluted, the great demand for oxygen may easily overstep the possibilities of atmospheric aeration, especially if there be bottom sludges, and a septic condition may develop. It sometimes happens, however, that the expected trouble does not materialize, or appears intermittently, with no variation meantime in quality or amount of sewage which might explain the matter—and the exposure to atmospheric oxygen has remained unchanged.

We believe that this unexpected lack of nuisance in a polluted environment is sometimes due to the oxygen-producing capabilities of submerged green plants. These may appear as visible masses of water-weed and of filamentous algae, or as very minute cells, of microscopic size, and visible only as a faint, greenish tint as some of the water in a graduate or similar clear-glass vessel, is inspected in a good light. To show that, contrary to general expectation, even such a small content of minute algal cells is capable of supplying a surprisingly large amount of oxygen to the surrounding water, is the

object of the following résumé of a study[4] recently carried out in our laboratory.

Our essential problem was this: Is a light or moderate content of minute algae, barely coloring the water, capable of supplying sufficient oxygen to meet the needs of polluted water, if unassisted meantime by atmospheric aeration?

Using a synthetic medium which, containing 10 milligrams of dextrose and of peptone per liter, was devised by Butterfield[5] and regarded as capable of sustaining a growth of around 10 to 15 million bacteria per cubic centimeter, this was inoculated in a carboy, with *B. aerogenes*. A second carboy was inoculated with "Alga-1"[6] in pure culture and bacteria-free, and a third carboy was inoculated with both *B. aerogenes* and Alga-1 in the same amounts used in the first and second carboys respectively. After vigorous shaking, followed by a half-hour quiescent period, contents of the three carboys were siphoned into three sets of 300 cc. bottles. Each bottle was completely filled and closed with a ground-glass stopper. Aseptic precautions were observed throughout.

Protection against external air was insured by the use of sterilized finger cots. One of these, half full of sterilized water, was superimposed over the "mushroom" top of each ground-glass stopper and pulled down until it enveloped the upper portion of the bottle neck, forming a collar of sterile water which completely surrounded the stopper at the point where it entered the bottle. These water seals were found necessary because of varying temperatures caused by the sunlight to which the cultures were exposed to insure the normal functioning of the alga cells.

Initial examinations were made in all cases, and thereafter every day for 5 or 6 days, then less often, in order to cover the total period of 14 to 17 days' duration of the experiment. These examinations included temperature, count of alga cells, agar plates for bacterial count and dissolved oxygen determination, using the Winkler method. The alga count was expressed in parts per million by volume. The cells were of such size (6 or 7 microns long and 5 microns in diameter) that about 50 were required to equal 1 cubic standard unit (a cube

[4] Detailed results of this study will be published shortly from our Cincinnati laboratory.

[5] A Note on the Relation Between Food Concentration in Liquid Media and Bacterial Growth. Public Health Reports, November 22, 1929, p. 2866.

[6] A minute green alga, similar to *Chlorella*, but not positively identified.

with an edge of 20 microns) and this cube, in turn, equals $\frac{1}{125000000}$ of a cubic centimeter. In all, five series of experiments were run, all with the same medium, the same bacteria, the same alga, and the same general technique. The first three series were incomplete in that they lacked the alga-only cultures.

The actual percent of sunshine hours affording sufficient light for normal plant activity varied considerably in the five experiments, due to weather fluctuations. In one experiment, a preponderance of dark, cloudy days resulted in only 10 percent of the total time being suitable for photosynthetic activity. In another experiment the sunshine hours amounted to 19 percent, and in another, about 25 percent. However, these natural variations of weather are what we are bound to encounter in the study of natural streams. The results of our experiments are, therefore, the more representative of actual stream economy because of our use of natural conditions as to available sunlight.

TABLE 1

History of dissolved oxygen in cultures of bacteria only, of bacteria and alga-1 and of alga-1 only, with no atmospheric aeration meantime.

DAYS	BACTERIA ONLY			BACTERIA AND ALGA-1			ALGA-1 ONLY	
	Temp.	Bacteria in 1 cc.	D. O.	Bacteria in 1 cc.	D. O.	Alga in 1 cc. (by volume)	D. O.	Alga in 1 cc. (by volume)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	°C.	*thousands*	*p.p.m.*	*thousands*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*
0	22.0	18.9	8.52	22.6	8.50	4.4	8.40	5.4
1	24.5	7020	4.33	6255	4.67	11.3	8.64	11.6
2	23.5	11650	3.19	11450	4.11	11.3	9.02	16.5
3	29.0	10950	3.03	11300	4.78	24.0	12.38	61.2
4	23.5	10850	2.36	11200	3.34	24.2	12.17	93.2
5	25.0	13700	2.39	13000	4.92	32.1	12.75	93.7
7	27.0	9875	1.90	8775	4.79	39.6	12.66	145.2
9	28.0	7000	0.89	6435	5.35	45.5	12.69	134.4
11	23.0	7950	0.02	7200	5.28	22.2	12.96	111.9
14	30.0	3860	0.19	1805	7.17	26.9	12.77	124.3
17	24.0	3750	0.00	2445	7.43	24.0	14.56	126.0

All bottles (except certain check cultures stored in darkness in the 20°C. incubator), were placed in a south window where such sunlight as was available passed through ordinary window glass of medium quality, and also through the white glass of the 300 cc. cylindrical bottle, before coming in contact with the alga cells in the culture.

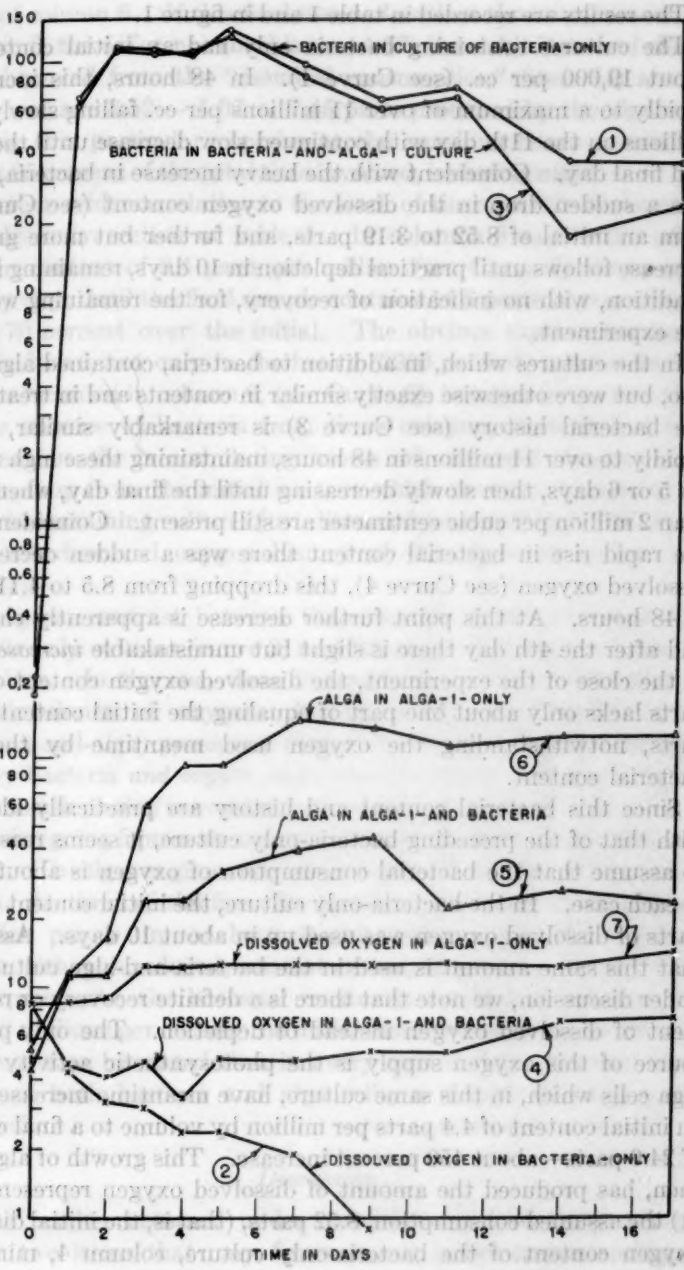

FIG. 1. GRAPHIC PRESENTATION OF THE DATA IN TABLE 1

The results are recorded in table 1 and in figure 1.

The cultures containing bacteria only had an initial content of about 19,000 per cc. (see Curve 1). In 48 hours, this increased rapidly to a maximum of over 11 millions per cc. falling slowly to 8 millions on the 11th day with continued slow decrease until the 17th and final day. Coincident with the heavy increase in bacteria, there was a sudden drop in the dissolved oxygen content (see Curve 2) from an initial of 8.52 to 3.19 parts, and further but more gradual decrease follows until practical depletion in 10 days, remaining in this condition, with no indication of recovery, for the remaining week of the experiment.

In the cultures which, in addition to bacteria, contained alga cells also, but were otherwise exactly similar in contents and in treatment, the bacterial history (see Curve 3) is remarkably similar, rising rapidly to over 11 millions in 48 hours, maintaining these high values for 5 or 6 days, then slowly decreasing until the final day, when more than 2 million per cubic centimeter are still present. Coincident with the rapid rise in bacterial content there was a sudden decrease in dissolved oxygen (see Curve 4), this dropping from 8.5 to 4.11 parts in 48 hours. At this point further decrease is apparently checked, and after the 4th day there is slight but unmistakable *increase* until, at the close of the experiment, the dissolved oxygen content of 7.43 parts lacks only about one part of equaling the initial content of 8.5 parts, notwithstanding the oxygen used meantime by the high bacterial content.

Since this bacterial content and history are practically identical with that of the preceding bacteria-only culture, it seems reasonable to assume that the bacterial consumption of oxygen is about equal in each case. In the bacteria-only culture, the initial content of 8.52 parts of dissolved oxygen was used up in about 10 days. Assuming that this same amount is used in the bacteria-and-alga culture now under discussion, we note that there is a definite recovery or replacement of dissolved oxygen instead of depletion. The only possible source of this oxygen supply is the photosynthetic activity of the alga cells which, in this same culture, have meantime increased from an initial content of 4.4 parts per million by volume to a final content of 24.0 parts—about 450 percent increase. This growth of alga cells, then, has produced the amount of dissolved oxygen represented by (1) the assumed consumption, 8.52 parts, (that is, the initial dissolved oxygen content of the bacteria-only culture, column 4, minus the final content in this same column) plus the excess shown in the final

item of column 6. If this final item is *less* than the initial amount in column 6, the difference (in this case 1.07) is a debit item and should be subtracted from the "assumed consumption" (item (1) above). Thus we have 8.52 − 1.07 = 7.45 parts produced by the alga cells. During this particular experiment the sunshine hours constituted about 25 percent of the total time involved, including night.

Further evidence relative to the work of the alga cells is shown by the alga-only section of table 1. In columns 8 and 9 the initial oxygen content of 8.4 parts per million (see Curve 7) shows gains day by day, until the final sample contains 14.6 parts, a gain of more than 70 percent over the initial. The obvious explanation meantime is found, not only in the heavy (2200 percent) increase in alga cells as recorded in column 9, (see Curve 6), but also in the fact that, in the absence of bacteria from these cultures, there is but little demand on the accumulating stores of dissolved oxygen. The sudden drop from the initial content which shows so plainly in the bacteria-containing cultures just discussed (curves 2 and 4) is absent from the dissolved oxygen history of the alga-only culture (see curve 7).

The great contrast between the essential picture shown by the bacteria-only cultures (curve 2) and the alga-only cultures (curve 7), is obvious. In the one, there is oxygen depletion; in the other, a superabundance of oxygen. Meantime the combination set-up (bacteria-and-alga) presents a picture (curve 4) of oxygen consumption by bacteria *and oxygen replacement* by algal activity, with the result that depletion is avoided by a wide margin of safety.

The foregoing figures are taken from one experiment only, of a series of five. The figures given are fairly representative of all the experiments. In three of the five, the bacterial maximum did not exceed 9 million per cc. in the bacteria-only cultures, and the dissolved oxygen, although reduced, was not entirely depleted. In two of the five experiments, the bacterial maximum reached 10 millions and even 13 millions per cc. and the initial dissolved oxygen was all used. It should also be stated that in every one of those cultures which contained both bacteria and alga cells, a surplus of oxygen was produced.

Discussion

These results, obtained under conditions of laboratory control, suggest two items that may figure in our better understanding of dissolved oxygen as it exists in our natural streams and water bodies.

A. If algae be present a measurable amount of pure oxygen is usually produced thereby within the water. Under natural conditions, this water is in contact with the atmosphere, which is a mixture of gases, essentially 4 parts nitrogen and 1 part oxygen. The water, having a given "demand" for oxygen will necessarily satisfy this demand by absorption from the stock or supply of oxygen available.

If this absorption takes place from the atmospheric supply, at the water surface, such absorption must be in conformity with the fact that this oxygen, constituting about 21 percent of the atmosphere, is subject to a vapor pressure of only one-fifth that of pure oxygen. If absorption takes place from the alga-produced supply already within the water, this supply, being pure, has a vapor pressure five times that of the atmospheric supply.

Discussing the amount of certain gases dissolved in natural waters, Whipple and Parker[7] say. "In a mixture of gases, the quantity of any one dissolved depends on the vapor pressure of that gas, regardless of the others. Thus water at 0°C. will dissolve 41.14 cc. per liter, of oxygen if exposed to pure oxygen (at one atmosphere) but exposed to air (which is one-fifth oxygen) it will absorb 41.14 cc. of oxygen under one-fifth the pressure, hence one-fifth as much by weight as in the first case." (Quotation from an abstract of Whipple's paper.)

In their exhaustive study of Wisconsin lakes, Birge and Juday[8] state, (p. 25), "In a mixture of gases, such as the air, the absorption of each gas is independent of all the other gases present and is proportional to the pressure exerted by that gas."

Birge and Juday very frequently found the largest quantities of dissolved oxygen (100 to 300 percent of saturation) not at the surface, but at depths varying from 1½ meters to 5 meters at which depths, in these clear waters, there was sufficient light to enable the algae to function. In several of these instances, the quantity of algae was considerably greater at these depths than in the surface waters.

It is well to ponder these several factors in the situation: In nature, algae are usually present. These produce pure oxygen within the water, in the presence of sunlight. The water, presumably polluted,

[7] Amount of Oxygen and Carbon Dioxide Dissolved in Natural Waters, and Effect on Microscopic Organisms. By G. C. Whipple and H. N. Parker. Trans. Amer. Microscopical Society, 1901, p. 103.

[8] The Dissolved Gases of the Water and Their Biological Significance. By E. A. Birge and Chancey Juday (1911). Bull. XXII Wisconsin Geological and Natural History Survey.

has in consequence an oxygen demand. The atmosphere, 4 parts nitrogen and 1 part oxygen, overlies the water and constitutes a continuous source of oxygen, night and day. But absorption of a given gas from a mixture "is proportional to the pressure exerted by that gas." This would appear to give to the pure oxygen within the water a probability of absorption about 5 to 1 over the probability of absorption of oxygen from the atmospheric mixture, and although this latter has the unquestioned advantage of being present at all times regardless of sunlight, the practical fact remains that the samples utilized to obtain our dissolved oxygen data are, as a rule, collected in daytime, when algae are active.

Our query then: Is the dissolved oxygen content of a natural water as usually ascertained, a result of algal activity or of atmospheric aeration? Are both sources of oxygen equally responsible?

Meantime, it is true that algae or other submerged plants produce excess oxygen during the hours of sunlight only. The process is checked on dark, cloudy days, and so far as we know is entirely absent at night. At such times oxygen demand must necessarily be concerned with the oxygen-and-nitrogen mixture, the atmosphere.

In the last analysis it matters little, or perhaps not at all, where the oxygen comes from. We are duly grateful if there is enough present, regardless of its source. As a rule, however, it is regarded as coming chiefly from the atmosphere. Perhaps this is not always the case. One purpose of this paper is to point out the possibility that even the small quantity of algal life so frequently present is capable of producing sufficient oxygen in situ to produce saturation if escape to the atmosphere is prevented. This result was obtained repeatedly, but under the conditions of the experiment already set forth, i.e. in effect a highly polluted water, but containing bacteria of one kind only, and a minute alga of one kind only. The varied assortment of bacteria, of algae, of spores, and of protozoa usually found in a normal water was absent. Whether, with such content, the normal contingent of algal cells or other chlorophyll-bearing organisms present will be able to perform so heroically remains to be ascertained.

In this connection, it may be said that routine samples of the Illinois River very frequently contained a greater quantity[9] of algal cells than was required to produce the results recorded in our experi-

[9] A Study of the Pollution and Natural Purification of the Illinois River. II. The Plankton and Related Organisms. Public Health Bulletin No. 198. See Table No. 54.

ments. Moreover, these figures do not include masses of submerged algae and larger water plants that must necessarily increase greatly the output of plant-made oxygen, as in the Potomac River.

B. We would again point out, as we did some years ago[10] the very marked effect of submerged green plants, plus sunshine, on the dissolved oxygen content of the water—and the resulting great differences in samples collected on sunny days as compared with cloudy day samples, or afternoon samples as compared with morning samples. If the dissolved oxygen content of the water is to be used as an index, it must be reliable and truly representative, and the *time* of collection must be selected with the same extreme care that we use in the selection of the *place* where the sample is to be collected. This essential fact has been further indicated in no uncertain terms by the studies of Rudolfs and Heukelekian,[11] by Mohlman and his associates,[12] by Streeter,[13] by Olson,[14] and by Hubbs.[15] Not only should the deposits of decomposable sludge be recognized for their potential and actual effect on the oxygen expenditure of the stream, as contended by Mohlman and by Streeter, but the somewhat analogous content of resident submerged plant life and of microscopic algae should be adequately evaluated also, for their potential and actual effect on the oxygen *income* of the stream or water body concerned.

We may state in summarizing:

(1) Minute cells of green algae, sufficiently numerous to tint the water a scarcely perceptible green, and under average daily conditions as to sunlight, produced measurable amounts of dissolved oxygen.

(2) The medium used simulated heavily-polluted water, in that it contained sufficient dissolved organic matter to sustain a bacterial content which, in various separate experiments, reached maxima varying from 5 to 13 millions per cc. However, only one kind of

[10] Potomac Plankton and Environmental Factors. In Hyg. Lab. Bulletin No. 104, p. 168–174, 1916.

[11] Effect of Sunlight and Green Organisms on Reaeration of Streams. Industrial and Engineering Chemistry, 23: January, 1931.

[12] Technic of Stream Pollution Investigations. Industrial and Engineering Chemistry, 23: February, 1931.

[13] The Effects of Sewage Discharge on Streams. Sewage Works Jour., III, October, 1931.

[14] Some Observations on the Interrelationships of Sunlight, Aquatic Plant Life and Fishes. Minnesota State Board of Health.

[15] Sewage Treatment and Fish Life. Sewage Works Jour., V: November, 1933.

bacterium was present, and there were no protozoa, predatory or otherwise.

(3) All cultures were in completely filled bottles. Atmospheric aeration was eliminated. Duration of the experiments varied from 10 to 17 days.

(4) Cultures containing bacteria only showed serious decrease in dissolved oxygen, this sometimes being entirely depleted.

(5) Cultures containing the minute algae in addition to the bacteria showed similar decrease of initial dissolved oxygen, but a program of recovery and replacement soon developed, becoming noticeable about the third day, when dissolved oxygen began to increase, coincident with increase in number of alga cells. This oxygen always prevented depletion by a wide margin, and sometimes produced supersaturation.

(6) Cultures containing no bacteria, but alga cells only, showed no decrease of initial dissolved oxygen—but a progressive increase, corresponding in general with the daily increase in alga cells.

(7) Check cultures in darkness in the 20°C. incubator showed (a) growth of bacteria similar to that in the cultures exposed to light, (b) no increase, or slight increase, of alga cells, (c) no replacement of dissolved oxygen.

(8) In natural waters, when algae are present and active, the oxygen produced thereby, being essentially pure, has a vapor pressure about 5 times as great as does the atmospheric oxygen. Absorption of a gas being proportional to its vapor pressure, it seems probable that the dissolved oxygen content as usually ascertained from samples collected during the day may contain a large proportion of alga-produced oxygen.

(9) In order that dissolved oxygen samples may be truly representative of average conditions in the stream, not only the sampling point, but also the hour of collection must be carefully chosen with reference to possible excess oxygen production on sunny days by submerged plants.

STUDY OF SELECTIVE MEDIA FOR COLI-AEROGENES ISOLATION

By C. C. Ruchhoft (*Bacteriologist, Sanitary District, Chicago, Ill.*) and John F. Norton (*Upjohn Company, Kalamazoo, Mich.*)

During the past few years a number of promising selective media for coli-aerogenes group isolation have been developed. These media are being used in many laboratories, although they have not been adopted in Standard Methods. A number of these media have been included in this study to determine the feasibility of using a more selective medium than lactose broth in Standard Methods without sacrificing sensitivity to any strains of the coli-aerogenes group. This study has been divided into three parts. The first step was to study the comparative coli-aerogenes productivity or growth response with a variety of strains. The second was to check the inhibitive qualities of these media on some of the common organisms encountered in water analysis which give false presumptive tests in lactose broth. If any of the media prove advantageous during the first steps of this study practical tests will be carried out. At the present time the first section of the study is practically complete and the second part is well under way.

All of the work was performed in a number of coöperating laboratories for the committee. The coöperators on the study include the following: Leo F. Ey and Rosemary Bole, *Ohio Department of Health;* Michael A. Farrell, *Pennsylvania State College;* F. W. Gilcreas, *New York State, Department of Health;* R. F. Goudey and Madeline Lynch, *Department of Water and Power, Los Angeles;* Murray P. Horwood and C. G. Dunn, *Massachusetts Institute of Technology;* Bernard H. Jeup and Marion S. Campbell, *Indiana Division of Public Health;* Stewart A. Koser and Raymond Spoelstra, *University of Chicago;* A. L. MacNabb and A. D. McClure, *Ontario Department of Health;* Jane H. Rider, *Arizona State Laboratory;* Cassandra Ritter, *Kansas Board of Health;* Col. J. T. Siler and Major H. R. Livesay, *Army Medical School;* Robert Spaulding Spray, *West Virginia University;*

Fred W. Tanner, *University of Illinois;* John L. White and R. E. Noble, *Chicago Board of Health;* and H. A. Whittaker and George O. Pierce, *Minnesota Department of Health.*

TABLE 1

Media

MEDIUM	MATERIALS IN GRAMS PER LITER	AMOUNT OF DEHYDRATED MEDIA PER LITER AND MEDIA PER TUBE	STERILIZATION
Lactose broth (standard methods)	Beef extract 3.0; peptone 5.0; lactose 5.0	13.0 grams per liter. 10 ml. per tube	15 lbs. for 15 min.
Fuchsine lactose broth	Beef extract 3.0; peptone 5.0; lactose 5.0; basic fuchsine 0.015	13.0 grams. 10 ml. per tube	15 lbs. for 20 min.
Buffered lactose broth	Beef extract 3.0; peptone 5.0; lactose 5.0; dipotassium phosphate 2.0	15 grams. 10 ml. per tube	15 lbs. for 15 min.
M.B.-B.C.P. broth (Lauter and Dominick)	Beef extract 3.0; peptone 7.8; lactose 4.7; dipotassium phosphate 1.7	For 1/10 ml. sample portions 18.4 grams per liter 15 ml. per tube	15 lbs. for 20 min.
	Potassium dehydrogen phosphate 0.3; erythosen (L-D) 0.0064; methylene blue (L-D) 0.064; brom cresol purple 0.01	For 1 ml. sample portions 19.55 grams per liter 15 ml. per tube	
Brilliant green bile	Oxgall 20.0; peptone 10.0; lactose 10.0; brilliant green 0.0133	40 grams. 10 ml. per tube	15 lbs. for 15 min.
Crystal violet lactose broth (Salle)	Peptone 5.0; dipotassium phosphate 5.0; potassium dehydrogen phosphate 1.0; lactose 5.0; crystal violet 0.00143	16 grams. 10 ml. per tube	15 lbs. for 15 min.
Formate ricinoleate (Stark and England)	Peptone 5.0; lactose 5.0; sodium formate 5.0; sodium ricinoleate 1.0	16 grams. 10 ml. per tube	11 to 13 lbs. for 15 min.

The media included in the study were: standard lactose broth; buffered lactose broth; brilliant green bile broth; crystal violet broth;

fuchsine lactose broth; formate ricinoleate broth; and methylene blue-brom cresol purple broth.

All the media used were prepared and supplied through the courtesy of the Difco Laboratories. The approval of the proponent of each medium was obtained on all media used in these tests. The exact compositions and methods of preparing the media for these tests are shown in table 1.

The method used for determining the comparative coli-aerogenes productivity of the media is that described by Butterfield (1) and Hoskins (2). Detailed instructions on the procedure were worked out and sent to all coöperators to insure uniformity. Each coöperating laboratory made comparative tests on all media with three coli-aerogenes strains freshly isolated from waters. It was suggested that one of these strains might be a Bact. coli, one a Bact. aerogenes and if possible one an intermediate. All strains used in the tests were sent to the referee for differentiation. For the tests a standardized suspension of the test organism was prepared and 15 tubes of each of three decimal dilutions were plated for each medium. The attempt was made to plant the decimal dilutions so that the intermediate dilution of the standard broth would produce about half negative and half positive results. One test on a medium comprised the results from a total of 45 inoculations compared with the results of 45 similar inoculations into standard lactose broth. All incubations were made at 37°C for 48 hours. This procedure was advantageous in that it gave a fairly accurate estimation of the "most probable number" coli-aerogenes density, and also the planting and handling technique could be carried out by all coöperators without difficulties.

SUMMARY OF DATA

About 60 coli-aerogenes strains from various parts of the country have been used in these tests. Of the 49 strains that have been differentiated 20 were coli, 17 were aerogenes and 12 were irregular or intermediate. At first the results of the tests were summarized according to the differential classification of the organisms. A study of these results indicated that there was apparently no decided selective action by any of the trial media for any section of the coli-aerogenes group. None of these media showed any superior growth-promoting properties for the coli section of the group as compared with the aerogenes section. In each of the trial media some coli

strains grew very well, while others did not, and some aerogenes grew well while others did not. Consequently the summaries of the study have been combined and apply to the entire coli-aerogenes group.

TABLE 2

Percent of tests in which the Coli-aerogenes productivity of the trial medium was higher and lower than standard lactose broth

TRIAL MEDIA	NUMBER OF TESTS	PERCENT OF TESTS IN WHICH PRODUCTIVITY OF TRIAL MEDIUM WAS	
		Higher than by standard lactose broth	Lower than by standard lactose broth
Buffered lactose broth	46	26	61
Methylene blue-brown cresol purple broth	28	29	64
Fuchsine lactose broth	29	24	62
Brilliant green bile broth	49	18	69
Crystal violet broth	50	10	74
Formate ricinoleate	49	4	93

TABLE 3

Maximum and minimum comparative results of trial media

TRIAL MEDIUM	MAXIMUM COMPARATIVE RESULT			MINIMUM COMPARATIVE RESULT			RATIO MAX. PERCENT/ MIN. PERCENT
	M.P.N.		Percent of standard	M.P.N.		Percent of standard	
	Standard	Trial		Standard	Trial		
(1) Fuchsine broth	495,000	986,000	199	3,180,000	1,580,000	50.4	4.0
(2) M.B.-B.C.P. medium	1,210,000	3,130,000	259	3,170,000	792,000	25.0	10.3
(3) Buffered lactose broth	373,000	759,000	203	932,000	184,000	19.7	10.3
(4) Brilliant green bile	495,000	1,100,000	221	932,000	141,000	15.1	14.6
(5) Crystal violet	495,000	932,000	188	6,430,000	373,000	5.8	32.4
(6) Formate and ricinoleate medium	495,000	574,000	115	1,880,000	6,190	0.33	350.0

Table 2 shows the number of strains tested and the percentage of tests in which the productivity of each of the trial media was higher or lower than standard lactose broth. It is apparent that media of equal coli-aerogenes productivity will not always give equal density

indices. But in a series of tests, media of equal productivity should give as many results higher as lower than standard lactose broth. Table 2 shows that all these media have a lower productivity than lactose broth on most strains tested.

To illustrate further the effect of variable strains in any study of media productivity, the maximum and minimum productivity tests of each medium are shown in table 3. These data illustrate that in any study, with a very limited number of strains, the character of the

TABLE 4

Aggregate number of positive tubes obtained in all tests

MEDIA	TOTAL NUMBER OF TUBES IN EACH DILUTION	TOTAL NUMBER OF POSITIVE TUBES		
		Lower dilution	Intermediate dilution	Higher dilution
Buffered lactose broth	690	627	309	40
Standard lactose broth	690	633	345	63
M.B.-B.C.P.	420	378	162	27
Standard lactose broth	420	394	191	32
Fuchsine lactose broth	435	384	167	32
Standard lactose broth	435	403	193	29
Brilliant green bile broth	735	636	289	35
Standard lactose broth	735	660	357	72
Crystal violet broth	750	638	276	33
Standard lactose broth	750	678	384	73
Formate ricinoleate broth	690	463	129	11
Standard lactose broth	690	630	345	62

strains chosen for the experiment may have a very great effect on the conclusions reached. There are no standard coli-aerogenes strains and we have no assurance that any single laboratory strain will be representative of the entire group in productive ability in media.

The total positive tubes obtained in all tests in all dilutions are shown in table 4. From table 4 the percentage of positives which each medium produced compared with the lactose broth positives, was calculated. The results are shown in table 5. These percentages show the productivity in the media investigated. It will be

noted that the lower the comparative productivity of the medium the greater is the fall in the percentage from the lower to the higher dilutions. This table indicated that there is not a great difference in the productivity of the methylene-blue brom cresol purple, the buffered lactose broth, or the fuchsine broth. The productivity of brilliant green bile broth and crystal violet broth are also very similar but lower than the first three media. The formate ricinoleate medium has apparently a lower mean productivity than any of the others.

To obtain a single productivity index for this group of coli-aerogenes strains, the most probable number was calculated for the aggregate data for each medium as shown in table 4. This is not the

TABLE 5

Percent of positive tubes produced by each trial medium of the standard medium in each dilution by all strains

TRIAL MEDIUM	PERCENT POSITIVE TUBES OF NUMBER PRODUCED BY STANDARD			MEAN PERCENT
	Lower dilution	Intermediate dilution	Higher dilution	
Buffered lactose broth (pH 7.2)	99.0	89.7	63.5	83.7
Fuchsine lactose broth	95.2	86.6	110	97.2
M.B.-B.C.P.	96.0	84.8	84.5	88.4
Brilliant green bile	96.4	80.9	48.6	75.3
Crystal violet broth	94.2	72.0	45.2	70.5
Formate ricinoleate	73.4	37.4	17.2	42.7

mean most probable number for the data. To obtain the mean most probable number it would be necessary to determine the most probable number for each strain and then take the mean. The most probable number on the aggregate data is an empirical number which will differ from the mean most probable number, but it is just as reliable for the purpose of comparing the mean productivity of various media. The most probable number index for the aggregate data for each medium is shown in table 6. From the aggregate most probable number index a percentage productivity index was calculated and is also shown in table 6. On the basis of the percentage productivity index these media can be rated in the following order: standard lactose broth, fuchsine broth, methylene blue-brom cresol

purple broth, brilliant green bile broth, crystal violet broth and formate recinoleate broth.

The comparative coli-aerogenes productivity of these media can be judged on the basis of the data presented in tables 2, 3, 5, and 6.

TABLE 6

Most probable number index for the aggregate data and aggregate productivity index

TRIAL MEDIA	M.P.N. INDEX ON AGGREGATE DATA		PERCENT PRODUCTIVITY INDEX
	Standard	Trial	
Buffered lactose broth	399,000	344,000	86.0
Fuchsine	373,000	295,000	78.4
M.B.-B.C.P.	406,000	309,000	75.8
Brilliant green bile broth	362,000	271,000	75.0
Crystal violet broth	384,000	251,000	65.0
Formate ricinoleate	391,000	125,000	32.0

TABLE 7

Productivity rating

POSITION	BASIS OF RATING				GENERAL PRODUCTIVITY RATING
	Percent of tests in which productivity was lower than lactose broth (Table 2)	Ratio of maximum to minimum comparative result (Table 3)	Mean percent of positive tubes produced (Table 5)	Percent productivity index on aggregate data (Table 6)	
1	Buff. L. B.	Fuchsine	Fuchsine	Buff. L. B.	Fuchsine
2	Fuchsine	Buff. L. B.	M.B.-B.C.P.	Fuchsine	Buff. L. B.
3	M.B.-B.C.P.	M.B.-B.C.P.	Buff. L. B.	M.B.-B.C.P.	M.B.-B.C.P.
4	B.G.B.B.	B.G.B.B.	B.G.B.B.	B.G.B.B.	B.G.B.B.
5	C.V.B.	C.V.B.	C.V.B.	C.V.B.	C.V.B.
6	Form. Ricin.	Form. Ricin.	Form. Ricin.	Form. Ricin.	Form. Ricin.

Buff. L. B. = Buffered lactose broth pH 7.2. Fuchsine = Fuchsine lactose broth. M.B.-B.C.P. = Methylene blue-brown cresol purple broth. B. G. B. B. = Brilliant green bile broth. C.V.B. = Crystal violet broth. Form. ricin. = Formate recinoleate broth.

The media have been rated from the data presented in table 7 and a mean rating derived. On the basis of productivity the trial media are rated in the following order from highest to lowest: (1) fuchsine broth (2) buffered lactose broth (3) methylene blue brom cresol

purple broth (4) brilliant green bile broth (5) crystal violet broth and (6) formate ricinoleate broth The productivity differences in the first three media are small. The last three media are decidedly more inhibitive and there is no question about their relative positions.

The study of these media, with interfering organisms not members of the coli-aerogenes group, is not complete, but partial reports on three organisms may be made at this time. On the basis of three tests with two strains of Cl. welchii and two tests with Cl. tertium these media are rated on their desirability (inhibitiveness to numbers of these organisms) in the following order (1) formate ricinoleate (2) crystal violet broth (3) fuchsine broth (4) brilliant green bile broth (5) buffered lactose broth (6) methylene blue-brom cresol purple (7) standard lactose broth. The first four of these media are all very much superior to lactose broth in their ability to inhibit these strains. The formate ricinoleate medium will not grow Cl. welchii or Cl. tertium regardless of the number inoculated into it. The buffered lactose broth and methylene blue-brom cresol purple broth are very little better than standard lactose broth in inhibiting these anaerobes.

Three strains of B. aerosporus have been investigated. Fuchsine broth, methylene blue-brom cresol purple broth, brilliant green bile broth, crystal violet broth and formate ricinoleate broth were all very much more inhibitive than standard lactose broth. Buffered lactose broth, however, is a better medium than lactose broth for these organisms.

SUMMARY AND CONCLUSIONS

It has been shown that all of the trial media are less productive of the coli-aerogenes group than standard lactose broth and that the order of their mean productivity from highest to lowest is as follows: (1) standard lactose broth (2) fuchsine lactose broth (3) buffered lactose broth (4) methylene blue brom cresol purple broth (5) brilliant green bile broth (6) crystal violet broth and (7) formate ricinoleate broth.

Buffered lactose broth is as good a medium for Cl. welchii, Cl. tertium and B. aerosporus as standard lactose broth and is therefore in this respect no improvement as a selective medium.

Methylene blue-brom cresol broth is apparently a good medium for Cl. welchii and Cl. tertium and is in this respect not so desirable.

Brilliant green bile broth, crystal violet broth and formate ricinoleate broth, while very selective, appear to be too inhibitive for use

as primary isolation media. Any or all of these might be used to advantage in the confirmation procedure. The brilliant green bile medium has been carefully studied as a confirmatory medium. Studies on crystal violet broth and formate ricinoleate broth for this purpose would be valuable.

Of all these media only the fuchsine broth and possibly the methylene blue-brom cresol purple broth seem worthy of further study as primary isolation media.

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THE RELATIVE PRODUCTIVITY OF CERTAIN CULTURE MEDIA

By R. E. Noble

(From the Bureau of Laboratories, Board of Health, Chicago, Ill.)

Butterfield (1) and Hoskins (2) have presented a method for comparing quantitatively the relative productivity of a number of liquid media, or direct plating solid media, or both. Their efforts have yielded one of the most sensitive and accurate methods developed for the purpose. It requires only a limited number of organisms for testing, and is based on a substantial number of tubes in three or more dilutions, rather than on mass inoculation, or on the conventional single tube series of dilutions. It is therefore superior to the latter methods.

This newer procedure has been used by us in making a preliminary productivity evaluation of certain proposed liquid media in comparison with standard lactose broth (3); and for a similar comparison between standard lactose broth and brilliant green lactose bile broth, using polluted Lake Michigan water (4). The earlier work, reported only in part, was done with a single stock strain of Bacterium coli of fecal origin.

It has heretofore been difficult to compare fermentation tube indices derived from a dilution series with direct plate indices on a fair basis because the former are essentially estimates, while the latter are actual counts and hence more nearly accurate. For example, some feel that standard lactose broth, planted in parallel with standard plain nutrient agar plates, would generally yield a higher index than the latter, due to the effect of positive tubes in the higher dilutions. There seems to be some basis for this view. With several tubes in each dilution, however, the Hoskins probability formula minimizes the magnifying effect of dilution thus rendering the derived "most probable number" comparable to the corresponding direct plate count. Butterfield's work demonstrates this comparability when 50 fermentation tubes are used in a three-dilution series, in parallel with plain nutrient agar plates (1).

Since lactose broth is the standard medium, most workers feel that its productivity should be equaled or exceeded by any proposed substitute medium, both with raw waters and pure culture strains. Many liquid media have the disadvantage also of permitting the growth of organisms other than the coli-aerogenes group, when planted with raw water. The extraneous growth adversely affects the growth of many coli-aerogenes strains present, acting to reduce them in number, or sometimes to suppress them completely. This does not occur, of course, when pure cultures are used.

Selective direct plating media have the disadvantage of sometimes allowing the growth of border-line colonies, i.e., those difficult to identify definitely as belonging to the coli-aerogenes group. This will

TABLE 1

Percent productivity of various fermentation media compared to standard lactose broth

FUCHSIN LACTOSE, 1ST FORMULA	FUCHSIN LACTOSE, 2ND FORMULA	FORMATE RICINOLEATE	CRYSTAL VIOLET	BRILLIANT GREEN LACTOSE BILE	DIFCO LACTOSE	METHYLENE BLUE, BROM CRESOL PURPLE	BUFFERED LACTOSE BROTH (RUCHHOFT)
33.8	72.9	95.9	103.3	89.7	114.4	36.3	110.1
30.4	75.4	98.6	113.5	108.7	108.1	46.7	83.1
14.5	81.0	90.1	80.7	66.9	100.5	52.1	110.8
		70.4	71.6	82.3			
		42.4	47.5	96.4			
Total 78.7	229.3	397.4	416.6	444.0	323.0	135.1	304.0
Mean 26.2	76.4	79.5	83.3	88.8	107.7	45.0	101.3

depend on the incidence of these types in the water tested. Natural waters, also, vary with their geographical location.

When comparing a trial medium with the standard, it is expected that the resulting growth may be definitely greater, or definitely less, or approximately the same, as the standard medium, or it may sometimes be in irregular relationship to the standard, i.e., somewhat less productive, but not distinguishable without careful analysis of data from more tests. Such media are referred to herein as "border-line media."

RESULTS WITH A SINGLE PURE CULTURE STRAIN OF BACT. COLI

In table 1 are given the productivity ratios obtained with eight fermentation media tested in parallel with standard lactose broth in the

preliminary study (3). The ratios were derived from the lactose broth values taken as 100 percent. The fuchsin lactose broth (1st formula) and methylene-blue brom-cresol-purple broth ratios suggest that these two media are insufficiently productive to warrant further comparisons. Buffered lactose broth (Ruchhoft) and Bacto lactose broth, on the other hand, compare very favorably with the standard. The remaining media, fuchsin broth (2nd formula), formate-ricinoleate, crystal violet, and brilliant green lactose bile broths, appear to be relatively under-productive. Before definitely considering them so, however, the results must be examined more closely to see if they lie in the irregular or border-line class. In fairness to both the trial and standard media, two phenomena, viz., the normal variation in readings, and any genuine difference in productivity, must be distinguished and measured, if possible.

To determine experimentally the percent of variability of standard lactose broth readings found with the Butterfield-Hoskins procedure, this medium was tested in parallel with itself 15 times, using the same Bact. coli strain. Each time, two parallel sets of 150 tubes, 50 at each of three dilutions, were tested, and hence two sets of separate most probable numbers obtained. The 15 pairs of readings were then converted to percent by the reversible ratio method,[1] and the 30 readings then arranged in the order of magnitude. Figure 1 deals with the distribution of the ratios, showing the mean, standard deviation, and maximum values. In this arrangement of the data, the mean and standard deviation values are among the most practical measures of the distribution. The standard deviation may be defined as the computed value which, when added to or subtracted from the mean, falls at a point in the distribution so as to include approximately one-third of the items on either side of the mean. In this experimental distribution of standard lactose broth ratios, the mean is 102.2 percent, and the standard deviation range, DD, is 80.9 to 123.5 percent, while the extremes of the entire range are 66.8 and 149.6 percent respectively.

With this picture as a guide, one is now in a better position to compare the test ratios obtained with the trial media, fuchsin lactose

[1] Example: A and B = parallel readings.

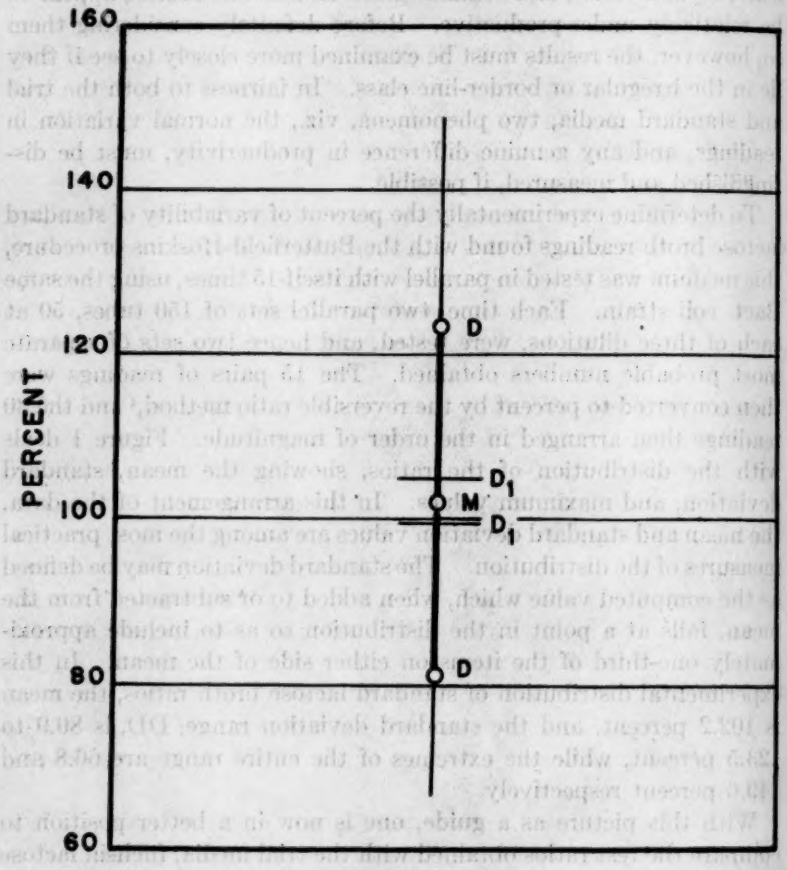
$\frac{A}{B}$ = one ratio, and

$\frac{B}{A}$ = the other ratio

broth (second formula), formate-ricinoleate, crystal violet and brilliant green lactose bile broths, given in table 1. These values,

FIGURE 1

RANGE OF LACTOSE BROTH RATIOS 30 B-H TESTS 1 STRAIN



M - MEAN
MD - ± STANDARD DEVIATION
MD_1 - ± PROBABLE ERROR OF MEAN

it is recalled, were all obtained with the same Bact. coli strain. The respective means of these media are materially less than 100 percent

or parity. The one of greatest magnitude, 88.8 percent, was obtained with brilliant green lactose bile broth.

There are two ways to consider these values. First, each trial ratio may be compared *individually* with the lactose broth range as a whole. On this basis only two items, namely, 42.4 by formate-ricinoleate and 47.5 percent by crystal violet broth, would fail to come within reasonable agreement with the standard medium; i.e., between 66.8 and 149.6 percent. From this it might be concluded that all the trial values except these, are merely chance variations in readings and do not necessarily reflect under-productivity in terms of standard lactose broth.

Secondly, the trial medium distribution of ratios may be compared as a whole with the lactose broth experimental distribution. Figure 1 indicates the normal scatter in the readings to be expected under the conditions of the test. Any appreciable differences in means of the distributions might be significant. This method of comparison seems more rational than the first named, since it attempts to allow for normal variability in the readings. However, the data of this kind in the series are few. Later experience leads to the belief that the results thus far should be regarded only as suggestive. Experience has also shown the necessity for obtaining a much larger collection of data for each medium. Furthermore, repeated tests with a single strain would not reveal much about the fitness of a given medium to grow *all* coli-aerogenes strains. Then, too, it is important to know whether *all* strains grow equally well in *all* the media under test, or whether certain strains grow well in one medium and poorly in another.

These considerations, therefore, called for a more extensive study of the problem. To meet this requirement, Bacto brilliant green lactose bile broth and Bacto buffered lactose broth (Ruchhoft) were chosen for further test in parallel with standard lactose broth. In addition, ferrocyanide-citrate agar and brilliant green lactose bile agar were also tested in parallel. Tests were made with 63 different coli-aerogenes strains according to the procedure below.

Materials

Standard lactose broth pH 7.0 prepared in our laboratory.

Brilliant green lactose bile broth and buffered lactose broth (Ruchhoft), prepared in dehydrated form and supplied without charge for use in these experiments by the Difco Laboratories.

Ferrocyanide-citrate agar and brilliant green lactose bile agar prepared by us, using the specially washed Difco agar. The basic fuchsin for brilliant green lactose bile agar and ferrocyanide-citrate agar is prepared with 95 percent alcohol.

Procedure

A sterile distilled water suspension of a pure culture, recently isolated, or a stock strain of Bact. coli or Bact. aerogenes, was first titred with ferrocyanide citrate agar. Knowing the direct plate count per ml. of the stock suspension, calculation determined the amount to use in preparing a 600.0 ml. buffered distilled water subsolution for the test, containing approximately 5.0 organisms per ml. Inoculations were then made as follows:

		Ml. of inoculum
1.	10 Ferrocyanide-citrate agar plates	10.0
2.	10 Brilliant green lactose bile agar plates	10.0
3.	150 Tubes of standard lactose broth	0.5, 0.1, 0.05
	150 Tubes of brilliant green lactose bile broth	0.5, 0.1, 0.05
	150 Tubes of buffered lactose broth	0.5, 0.1, 0.05
4.	10 Ferrocyanide-citrate agar plates	10.0
5.	10 Brilliant green lactose bile agar plates	10.0

In order to inoculate all three liquid media as nearly simultaneously as possible, the following planting sequence was used:

a. A tube of each medium inoculated with the 1st dilution, 0.5 ml.
b. A tube of each medium inoculated with the 2nd dilution, 0.1 ml.
c. A tube of each medium inoculated with the 3rd dilution, 0.05 ml.
d. A tube of each medium inoculated with the 3rd dilution, 0.05 ml.
e. A tube of each medium inoculated with the 2nd dilution, 0.1 ml.
f. A tube of each medium inoculated with the 1st dilution, 0.5 ml.

This order was followed until the 450 tubes were inoculated.

The brilliant green lactose bile agar was incubated 17–19 hours and all other media 42–48 hours. The number of positive and negative tubes in each fermentation medium, according to dilution, were recorded and fitted to the Hoskins formula for deriving the most probable number per ml. of suspension used. The most probable number with each fermentation medium and the direct plate count means were then compared with each other and with standard lactose broth on a percentage basis, taking the lactose broth value as 100 percent.

As already stated, it is necessary to distinguish between normal

TABLE 2

Ratios corresponding to the standard lactose broth readings taken as 100 percent

BRILLIANT GREEN BILE BROTH	BUFFERED LACTOSE BROTH (RUCHHOFT)	F-CYANIDE CITRATE AGAR	BRILLIANT GREEN BILE AGAR
230.0	65.0	805.0	435.0
157.3	119.7	95.6	96.3
149.2		141.1	130.7
145.6	73.4	46.6	39.8
141.0		140.5	136.9
133.2	83.0	87.4	94.4
128.3		101.4	105.6
125.7	84.3	105.0	101.5
124.3		112.8	119.7
121.6		136.0	132.1
117.6		103.6	111.7
117.0	93.0	92.8	106.3
115.6	117.0	96.6	104.2
115.1	86.1	95.7	110.6
114.7		105.8	125.1
109.8	91.8	81.8	81.5
108.3	102.4	88.4	84.2
106.3	80.9	165.0	157.2
105.6	101.6	76.4	58.9
105.5	109.8	111.6	99.2
105.0		94.5	89.4
102.1		73.2	63.6
102.0		107.8	114.5
98.8		108.2	113.0
98.7	114.1	95.5	90.6
96.7	99.1	83.2	84.4
95.9		92.9	98.3
95.6		119.6	104.4
95.4	93.9	182.4	71.7
94.9	119.2	108.2	87.5
94.1	114.6	90.8	93.8
94.1	77.8	59.3	68.1
93.7	112.5		
92.5	79.5	76.7	77.5
89.8	93.7	92.8	77.0

TABLE 2—*Concluded*

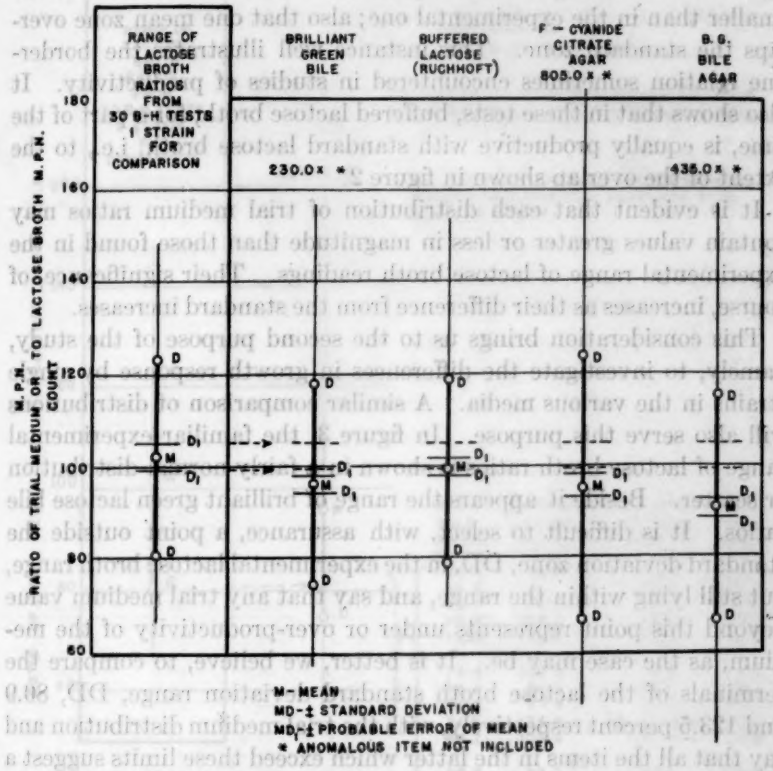
BRILLIANT GREEN BILE BROTH	BUFFERED LACTOSE BROTH (BUCHHOFT)	F-CYANIDE CITRATE AGAR	BRILLIANT GREEN BILE AGAR
88.5	93.0	87.4	80.0
88.0		49.7	71.8
88.0	145.6	87.9	98.3
87.0	82.6	173.8	91.3
86.3	72.1	86.9	100.3
85.8	97.4	101.4	106.1
85.7	153.1	83.8	85.1
84.7	86.4	78.1	76.9
84.4	87.4	77.3	83.1
84.1		83.9	138.7
83.8		84.6	92.8
83.7	130.1	158.5	104.1
82.9		58.8	39.6
82.3		68.0	67.4
81.6	117.3	102.2	89.7
80.4	90.8	71.0	62.5
79.8		100.9	105.6
76.7	78.3	73.2	77.1
76.4	108.6	58.4	62.6
76.0	112.0	86.6	80.0
75.4	100.0	97.8	79.8
73.6	99.3	78.2	109.3
71.4	77.4	63.3	56.7
71.2	135.2	No growth	90.0
69.7	105.4	70.6	55.6
69.3	93.5	83.3	62.2
64.4	129.0	115.8	103.8
61.4	75.6	64.5	66.6
56.9	79.1	68.8	50.6
No growth		147.0	132.1
	134.0		
	108.0		
	84.3		

variation in the readings and a genuine difference in productivity of the trial medium; also that a variety of coli-aerogenes strains would

doubtless better serve this purpose than a single strain. It is at this point that the experimental range of variation incident to standard lactose broth readings, figure 1, is helpful, if not indispensable.

FIGURE 2

RANGES OF PRODUCTIVITY RATIOS
63 COLI-AEROGENES CULTURES



RESULTS WITH A VARIETY OF FRESHLY ISOLATED AND STOCK COLI-AEROGENES STRAINS

In table 2 are tabulated, according to each medium, the individual ratios corresponding to the standard lactose broth readings which were taken as 100 percent. Figure 2 shows these data as distributions in the order of magnitude, with certain statistical landmarks to help emphasize the significant differences.

If the 15 lactose broth tests described above were repeated several times, then the mean, M, in figure 1, might be located anywhere

within MD_1 in either direction. This zone is called the range of probable error of the mean. It is not to be confused with the standard deviation, MD. MD_1 of the lactose broth experimental range of ratios is projected with broken lines upon the respective trial media ranges of brilliant green bile, buffered lactose, ferrocyanide-citrate agar and brilliant green bile agar. It is seen that all means are smaller than in the experimental one; also that one mean zone overlaps the standard zone. This instance well illustrates the borderline relation sometimes encountered in studies of productivity. It also shows that in these tests, buffered lactose broth, for a part of the time, is equally productive with standard lactose broth, i.e., to the extent of the overlap shown in figure 2.

It is evident that each distribution of trial medium ratios may contain values greater or less in magnitude than those found in the experimental range of lactose broth readings. Their significance, of course, increases as their difference from the standard increases.

This consideration brings us to the second purpose of the study, namely, to investigate the differences in growth response by single strains in the various media. A similar comparison of distributions will also serve this purpose. In figure 3, the familiar experimental range of lactose broth ratios is shown in a fairly normal distribution or scatter. Beside it appears the range of brilliant green lactose bile ratios. It is difficult to select, with assurance, a point outside the standard deviation zone, DD, in the experimental lactose broth range, but still lying within the range, and say that any trial medium value beyond this point represents under or over-productivity of the medium, as the case may be. It is better, we believe, to compare the terminals of the lactose broth standard deviation range, DD, 80.9 and 123.5 percent respectively, with the trial medium distribution and say that all the items in the latter which exceed these limits suggest a difference in degree of productivity in relation to the standard.

To illustrate, all brilliant green lactose bile broth values less than 80.9 percent, the lower limit of the lactose broth standard deviation are bracketed and tabulated. Beside these are also tabulated the corresponding values by the other trial media. This brings out in another way the contrast in degree of growth response by some strains, in these media. Thus, one strain shows a brilliant green bile value of 71.2 percent but no growth in ferrocyanide-citrate agar. Another strain shows no growth in the bile broth but does give a ferrocyanide-citrate agar value of 147 percent. Of the 15 low value

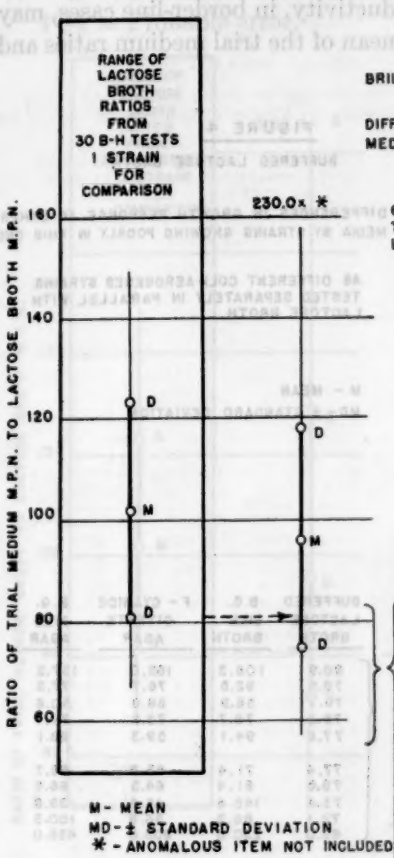
strains in the brilliant green lactose bile distribution, 8 strains give 11 values greater than 100 percent, scattered among the other media. Seven strains grew no better in certain of the other media. Similar comparisons are made with buffered lactose broth, ferrocyanide-citrate agar and brilliant green lactose bile agar in figures 4, 5, and 6.

FIGURE 3

BRILLIANT GREEN BILE BROTH

DIFFERENCES IN GROWTH RESPONSE TO OTHER MEDIA BY STRAINS GROWING POORLY IN THIS ONE.

63 DIFFERENT COLI-AEROGENES STRAINS TESTED SEPARATELY IN PARALLEL WITH LACTOSE BROTH.



B.G. BILE BROTH	BUFFERED LACTOSE BROTH	F-CYANIDE CITRATE AGAR	B.G. BILE AGAR
80.4	90.8	71.0	62.5
79.8	-	100.9	105.6
76.7	78.3	73.2	77.1
76.4	108.6	58.4	62.6
76.0	112.0	86.6	80.0
75.4	100.0	97.8	79.8
73.6	99.3	78.2	109.3
71.4	77.4	63.3	56.7
71.2	135.2	NO GROWTH	90.0
69.7	105.4	70.6	55.6
69.3	93.5	83.3	62.2
64.4	129.0	115.8	103.8
61.4	75.6	64.5	66.6
56.9	79.1	68.8	50.6
NO GROWTH	-	147.0	132.1

Similar analysis of the upper parts of the several distributions would show strains with a high productivity in one medium, and a low in one or more of the others. All test media reflected better growth for certain strains than lactose broth as indicated by values greater than 149.6 percent.

The foregoing treatment deals with several of the variabilities to

be expected under the conditions of these experiments, using pure cultures. One can picture, therefore, some of the further complexities to be considered when liquid media are planted with raw waters containing many organisms other than the coli-aerogenes group.

The extent of agreement in productivity, in border-line cases, may be determined by comparing the mean of the trial medium ratios and

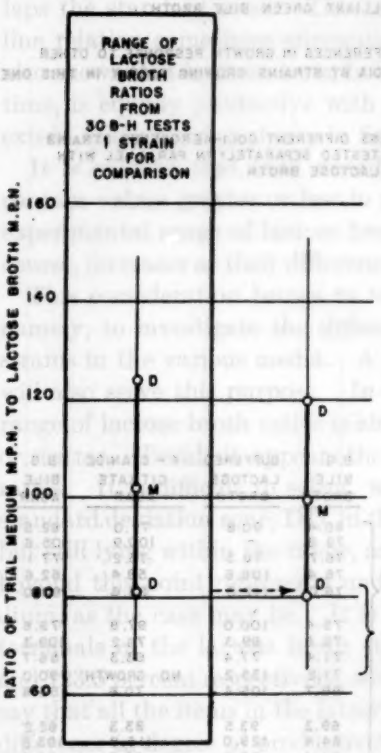


FIGURE 4

BUFFERED LACTOSE BROTH

DIFFERENCES IN GROWTH RESPONSE TO OTHER MEDIA BY STRAINS GROWING POORLY IN THIS ONE

48 DIFFERENT COLI-AEROGENES STRAINS TESTED SEPARATELY IN PARALLEL WITH LACTOSE BROTH

M - MEAN

MD - ± STANDARD DEVIATION

BUFFERED LACTOSE BROTH	B.G. BILE BROTH	F - CYANIDE CITRATE AGAR	B.G. BILE AGAR
80.9	106.3	165.0	157.2
79.5	92.5	76.7	77.5
79.1	56.9	68.8	50.6
78.3	76.7	73.2	77.1
77.8	94.1	59.3	68.1
77.4	71.4	63.3	56.7
75.6	61.4	64.5	66.6
73.4	145.6	46.6	39.8
72.1	86.3	86.9	100.3
65.0	230.5	805.0	435.0

its probable error with the mean of the lactose broth experimental ratios and its probable error. Then the probable error of the difference shows whether or not the trial medium will grow coli-aerogenes organisms better, or not as well, or to about the same degree as the standard medium. The formula for this determination appears below (5):

$$\sqrt{\left(\frac{0.67449\sigma}{\sqrt{N}}\right)_L^2 + \left(\frac{0.67449\sigma}{\sqrt{N}}\right)_T^2} = \pm \text{P.E.}_D$$

where σ = Standard deviation,

N = Number of items,

L = Lactose broth experimental distribution,

T = Trial medium distribution,

D = Difference between means,

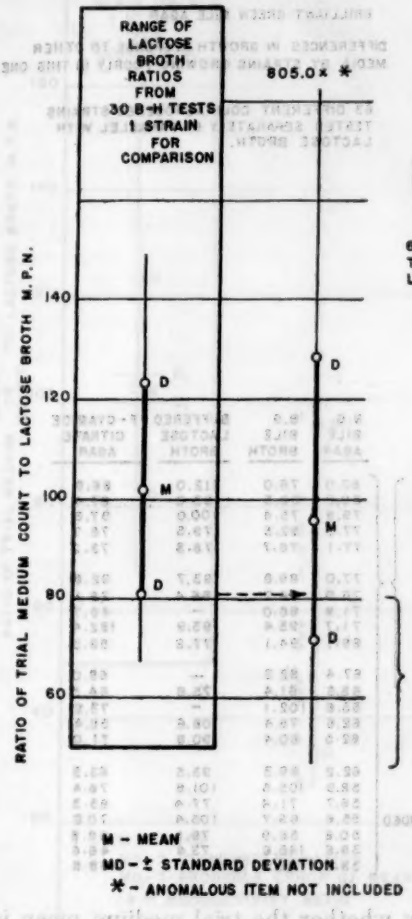
P.E. = Probable error.

FIGURE 5

FERROCYANIDE - CITRATE AGAR

DIFFERENCES IN GROWTH RESPONSE TO OTHER MEDIA BY STRAINS GROWING POORLY IN THIS ONE.

63 DIFFERENT COLI-AEROGENES STRAINS TESTED SEPARATELY IN PARALLEL WITH LACTOSE BROTH.

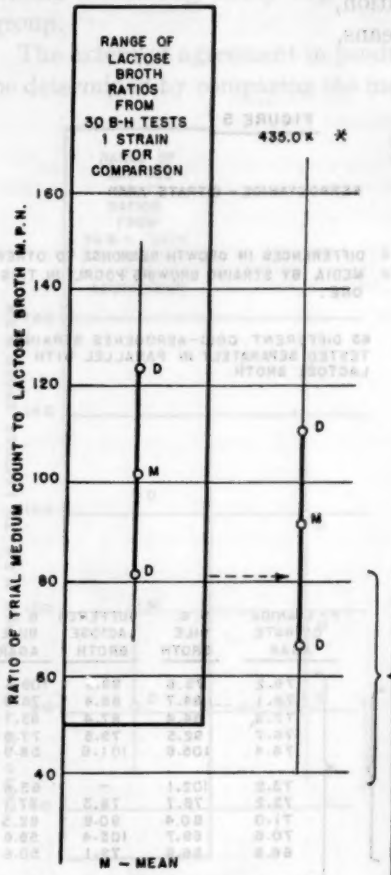


F-CYANIDE CITRATE AGAR	B. G. BILE BROTH	BUFFERED LACTOSE BROTH	B.G. BILE AGAR
78.2	73.6	99.3	109.3
78.1	84.7	86.4	76.9
77.3	84.4	87.4	83.1
76.7	92.5	79.5	77.5
76.4	105.6	101.6	58.9
73.2	102.1	–	63.6
73.2	76.7	78.3	77.1
71.0	80.4	90.8	62.5
70.6	69.7	105.4	55.6
68.8	56.9	79.1	50.6
68.0	82.3	–	67.4
64.5	61.4	75.6	66.6
63.3	71.4	77.4	56.7
59.3	94.1	77.8	68.1
58.8	82.9	–	39.6
58.4	76.4	108.6	62.6
49.7	88.0	–	71.8
46.6	145.6	73.4	39.8

Generally, when the difference between the mean of the trial medium and that of the experimental distribution is greater than three times the probable error of the difference, it indicates the trial me-

dium productivity is almost certainly greater or less than that of the standard medium, due to an inherent property of the medium itself rather than to chance variation. Whether the productivity is

FIGURE 6



BRILLIANT GREEN BILE AGAR

DIFFERENCES IN GROWTH RESPONSE TO OTHER MEDIA BY STRAINS GROWING POORLY IN THIS ONE.

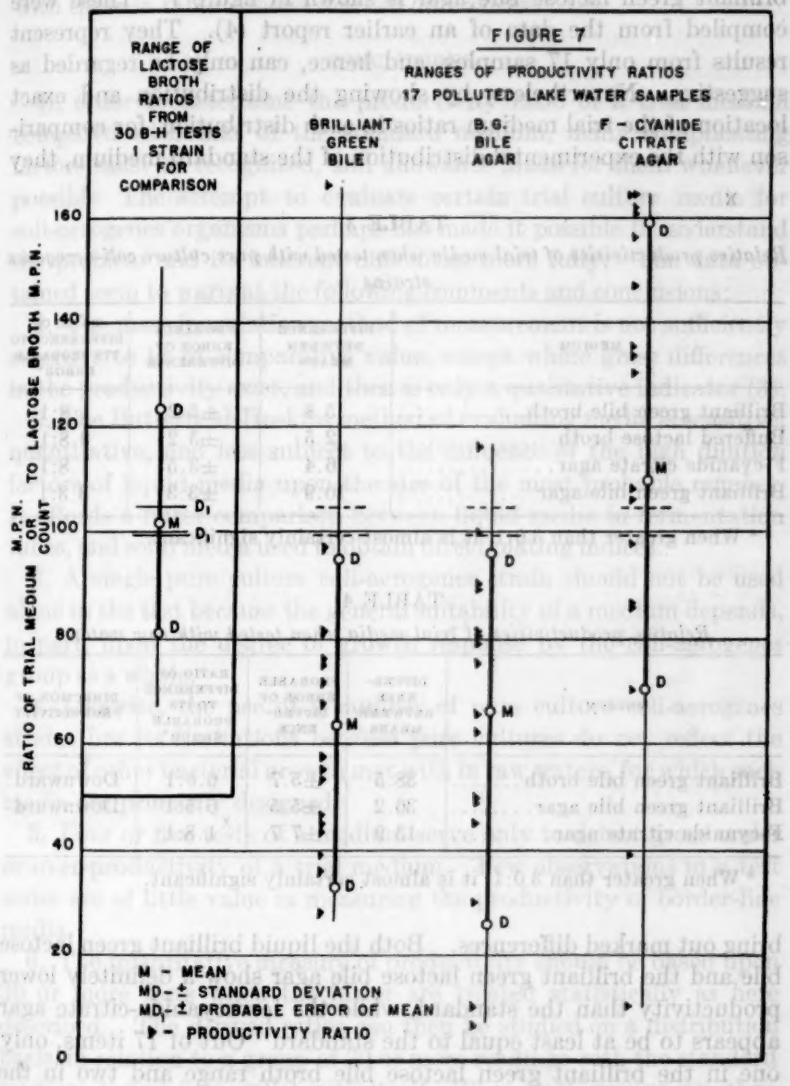
63 DIFFERENT COLI-AEROGENES STRAINS TESTED SEPARATELY IN PARALLEL WITH LACTOSE BROTH.

B.G. BILE AGAR	B.G. BILE BROTH	BUFFERED LACTOSE BROTH	F-CYANIDE CITRATE AGAR
80.0	76.0	112.0	86.6
80.0	88.5	93.0	87.4
79.8	75.4	100.0	97.8
77.5	92.5	79.5	76.7
77.1	76.7	78.3	73.2
77.0	89.8	93.7	92.8
76.9	84.7	86.4	78.1
71.8	88.0	–	49.7
71.7	95.4	93.9	182.4
68.1	94.1	77.8	59.3
67.4	82.3	–	68.0
66.6	61.4	75.6	64.5
63.6	102.1	–	73.2
62.6	76.4	108.6	58.4
62.5	80.4	90.8	71.0
62.2	69.3	93.5	83.3
58.9	105.6	101.6	76.4
56.7	71.4	77.4	63.3
55.6	69.7	105.4	70.6
50.6	56.9	79.1	68.8
39.8	145.6	73.4	46.6
39.6	82.9	–	59.8

greater or less is determined by whether the trial medium mean is above or below 100 percent.

Table 3 shows that by this treatment of these data, brilliant green lactose bile broth, buffered lactose broth and ferrocyanide-citrate agar have productivities equal to that of standard lactose broth. It

must be remembered that the equal productivities found in these cases, rest upon tests with pure culture strains only. This showing



might not occur when the trial medium is planted with raw water because of the influence of other bacteria on the growth of the coli-aerogenes group.

The extent to which raw water planting may alter the picture obtained with pure cultures in brilliant green lactose bile broth and brilliant green lactose bile agar is shown in figure 7. These were compiled from the data of an earlier report (4). They represent results from only 17 samples, and hence, can only be regarded as suggestive. Nevertheless, by showing the distribution and exact location of the trial medium ratios in each distribution, for comparison with the experimental distribution of the standard medium, they

TABLE 3

Relative productivities of trial media when tested with pure culture coli-aerogenes strains

MEDIUM	DIFFERENCE BETWEEN MEANS	PROBABLE ERROR OF DIFFERENCE	RATIO OF DIFFERENCE TO ITS PROBABLE ERROR*
Brilliant green bile broth	5.8	±3.2	1.8:1
Buffered lactose broth	2.5	±3.2	0.8:1
F-cyanide citrate agar	6.4	±3.5	1.8:1
Brilliant green bile agar	10.9	±3.3	3.3:1

* When greater than 3.0:1, it is almost certainly significant.

TABLE 4

Relative productivities of trial media when tested with raw water

MEDIUM	DIFFERENCE BETWEEN MEANS	PROBABLE ERROR OF DIFFERENCE	RATIO OF DIFFERENCE TO ITS PROBABLE ERROR*	DIRECTION OF PRODUCTIVITY
Brilliant green bile broth	38.5	±5.7	6.8:1	Downward
Brilliant green bile agar	36.2	±5.5	6.5:1	Downward
F-cyanide citrate agar	13.9	±7.7	1.8:1	

* When greater than 3.0:1, it is almost certainly significant.

bring out marked differences. Both the liquid brilliant green lactose bile and the brilliant green lactose bile agar show a definitely lower productivity than the standard, while the ferrocyanide-citrate agar appears to be at least equal to the standard Out of 17 items, only one in the brilliant green lactose bile broth range and two in the brilliant green lactose bile agar range were greater than 100 percent. Ferrocyanide-citrate agar, on the other hand, showed 11 items greater than 100.0 percent.

The measurements of trial media productivity compared to the standard medium, are given in table 4 Comparison of the values with those in table 3 shows marked differences.

CONCLUSIONS

In order to determine the productivity ratio of a trial medium compared with that of the standard medium, many complicating factors must be recognized, and allowance made for them whenever possible The attempt to evaluate certain trial culture media for coli-aerogenes organisms perhaps has made it possible to understand the problem and its inherent difficulties more fully. The data obtained seem to warrant the following comments and conclusions:

1. The mass inoculation method of measurement is not sufficiently sensitive to be of comparative value, except where gross differences in the productivity exist, and then is only a qualitative indicator (3).

2. The Butterfield-Hoskins method of evaluating media is sensitive, quantitative, and less subject to the influence of the high dilution factors of liquid media upon the size of the most probable number. It affords a fairer comparison between liquid media in fermentation tubes, and solid media used to obtain direct plating indices.

3. A single pure culture coli-aerogenes strain should not be used alone in the test because the general suitability of a medium depends, in part, upon the degree of growth response by the coli-aerogenes group as a whole.

4. Likewise, the use of a number of pure culture coli-aerogenes strains has its limitations because pure cultures do not reflect the effect of other bacterial growth met with in raw waters, for which such media are primarily designed.

5. Four or five tests of a medium serve only to detect gross under or over-productivity of a trial medium. Few observations in a test series are of little value in measuring the productivity of border-line media.

6. The quantitative measure of productivity should be based upon 30 or more tests when the latter are treated statistically as here described. The derived ratios can then be studied on a distribution basis, in relation to a group of 30 or more readings with the standard medium tested in parallel with itself. When both groups are thus treated alike statistically and compared, any genuine difference in productivity of a border-line medium may be detected.

7. A few data point to the likelihood that for more satisfactory

evaluation of a proposed coli-aerogenes culture medium, a variety of raw waters should constitute the test material, using the same procedure as here described.

8. In the tests with a variety of pure cultures, buffered lactose broth (Ruchhoft), for a part of the time, is just as productive as the standard lactose broth. The level of productivity for brilliant green lactose bile agar comes just outside the lower limit for lactose broth, by this method of measurement.

9. A considerable number of strains show marked differences of growth response according to the medium in which they are grown. Some grow poorly or not at all in one medium, while in another they grow as well or better than in the standard medium.

10. In these tests, the productivities of brilliant green lactose bile broth and brilliant green lactose bile agar are less when planted with raw lake water instead of pure cultures. The productivity of ferrocyanide-citrate agar, on the other hand, appears to be unaffected, making as good a showing in the aggregate as the standard medium. The data on this point, however, are only suggestive.

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THE PREPARATION OF FINE ANTHRACITE COAL FOR USE IN FILTER PLANTS

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In this paper the writer will attempt to explain, in detail, the method used in preparing fine anthracite coal for filtration purposes. Before discussing the preparation method, however, it would be well to describe briefly the feed to the Anthrafilt Preparation Plant, that is, the condition of the material to be prepared for filtration purposes.

This anthracite coal, which is made through a $\frac{3}{32}$-round mesh will show when sized over a nest of 12 Tyler standard screens, the distribution given in table 1.

In addition to this wide range of size, raw anthracite coal will carry approximately 20 percent ash, which must be reduced to 8 percent, or less, when the coal is to be used for filtration purposes. If the ash is not reduced, the finished product will have a variable specific gravity, and, of course, if this occurs the anthracite coal for filtration purposes is of much less value.

In preparing this material to size specifications, that is, effective size and uniformity coefficient, and at the same time to reduce the ash from 20 to 8 percent or less, the Rheolaveur process of coal preparation is used. In connection with this a Ferrarie Shaker is used at the discharge end of the Rheo, to aid in finished sizing.

This process, which has been used quite extensively in the preparation of European coals, depends entirely on the difference in specific gravity between coal and refuse or slate for its action.

In the case of the preparation of fine anthracite coal, this specific gravity difference is approximately 0.5 of a point, the coal having a specific gravity of 1.50 to 1.60 and the refuse having a specific gravity ranging from 1.85 to 2.00.

The process is briefly this: The feed coal is fed into a pitched chute, having a pitch of $2\frac{3}{4}$ inches to the foot, which is 14 inches wide and 24 inches deep, and through which water is being forced at a high velocity. As the feed coal passes down this pitched chute with the water,

primary classification takes place at the point where the pitch chute breaks into a new pitch of $\frac{7}{8}$-inch to the foot and here the heavy refuse is dropped out.

From here on over a 50 foot length of trough, boxes are located at intervals of 2 feet 10 inches in the bottom of the trough and small

TABLE 1

Distribution of sizes of anthracite coal fed to the Rheolaveur Process

TYLER MESH	CUMULATIVE PASSING
	percent
10	98.5
12	93.9
14	86.3
20	64.6
24	52.8
28	44.6
35	29.1
40	25.7
48	17.2
60	12.2
80	6.0
100	3.5
200	1.2
300	0.7
−300	0

Effective size, 0.21 mm.; and uniformity coefficient, 3.67.

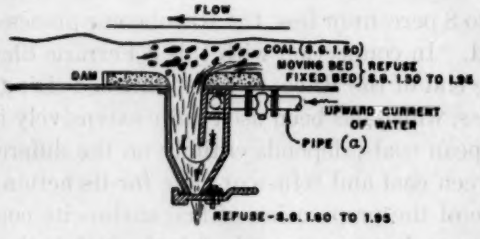

FIG. 1

dams, ranging in height of 1 to 4 inches progressively along the length of the chute, are located just after the box.

As the mixture of coal and refuse passes down the 50 foot length of chute and over the Rheo boxes (shown in figure 1), the heavy refuse drops out and the coal, being of lighter specific gravity, is carried over

the opening in the Rheo box by means of the vertical current of water supplied through pipe (a).

At the first box the vertical current of water is opened wide so that only the heavy refuse, which is traveling or sliding along the bottom of the chute and, of course, hits the dam, can be dropped out. The next box uses a less intense upward current, thus allowing some heavy refuse and some light refuse to be discarded. This process continues over the remaining 14 Rheo boxes with a decrease in vertical water

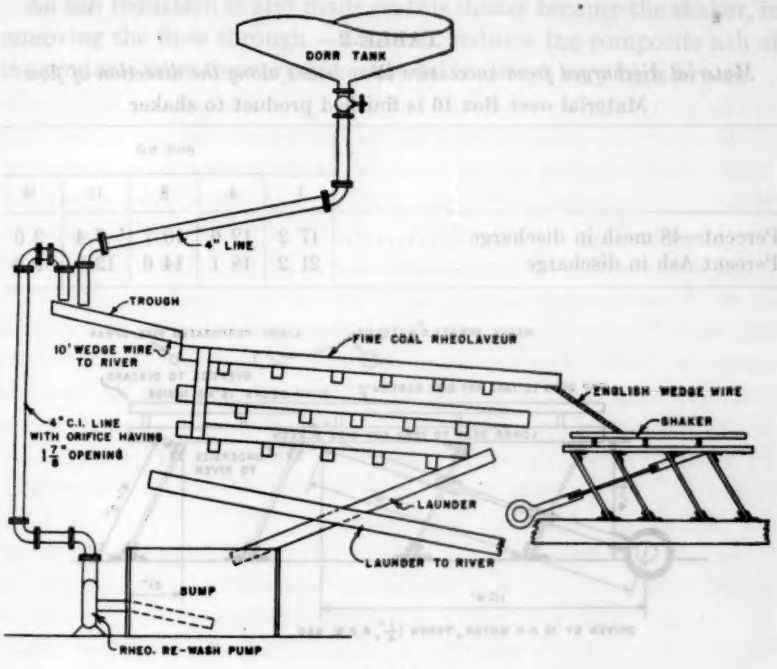

FIG. 2

velocity, until the last box discharges coal of approximately the same ash as that discharged over the end of the chute to the shaker. In short, as the feed coal passes over 16 successive boxes or traps, the ash is reduced by each box approximately three-quarters of one percent. (See fig. 2.)

The discarded material, or the material dropped out of the first trough, is collected in a secondary rewash trough, and passed to a collection sump where an over-flow launder removes some of the material of 60 mesh, and where a centrifugal pump forces the remain-

ing material back to the head of the plant for re-classification. The refuse, or discharge, from the rewash trough, of course, goes to the river.

The reduction in non-combustible material through 48 mesh, as we progress along the series of Rheo boxes, is shown in table 2. You will note that both the ash and material −48 mesh is decreased.

After the fine coal leaves the Rheo trough, it is carried over a 4 foot length of English wedge-wire pitched at 45°, which is in a sense a small

TABLE 2

Material discharged from successive Rheo boxes along the direction of flow

Material over Box 16 is finished product to shaker

	BOX NO.				
	1	4	8	12	16
Percent—48 mesh in discharge	17.2	12.6	10.7	6.4	2.0
Percent Ash in discharge	21.2	18.1	14.6	12.0	9.0

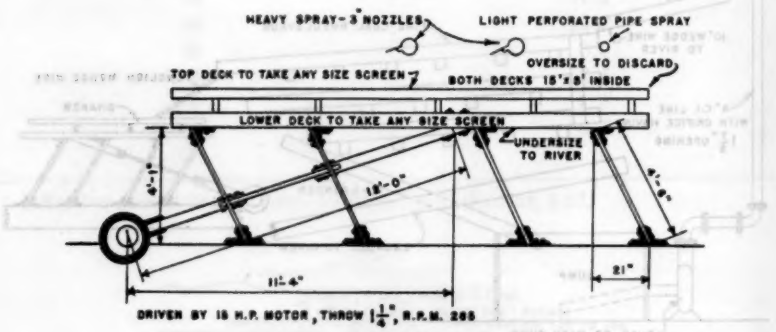
HEAVY SPRAY-3" NOZZLES
LIGHT PERFORATED PIPE SPRAY
OVERSIZE TO DISCARD
TOP DECK TO TAKE ANY SIZE SCREEN
BOTH DECKS 15"x 8' INSIDE
LOWER DECK TO TAKE ANY SIZE SCREEN
UNDERSIZE TO RIVER
18'-0"
11'-4"
21"
DRIVEN BY 15 H.P. MOTOR, THROW 1 1/4", R.P.M. 265

FIG. 3

self-cleaning bar screen, having a distance between bars of 0.246 mm. Here the fine anthracite is de-watered and the remaining high ash fines are discarded to the sewer.

From here on the process becomes one of specific sizing. You will remember that the feed material, in addition to containing 20 percent ash, also contained 17.2 percent −48 mesh. After the fine coal has been through this process of hydraulic classification the ash has been reduced to approximately 9 percent, and the fine material, or the material through −48, has been reduced to 2 percent.

The Ferrarie Shaker, which is used for the final sizing, is equipped with two decks so that both oversize and undersize can be discarded.

This shaker, figure 3, is also equipped with three removable jackets on the top deck, and five removable jackets on the bottom deck, so that by simply changing jackets any specifically sized product may be made. In addition to this, a series of water sprays above each deck aids in further sizing, because the intensity of the spray may be varied to drive the particles through the shaker jackets.

An ash reduction is also made on this shaker because the shaker, in removing the fines through −48 mesh, reduces the composite ash of the product, since the very fine material is always very high in ash.

A COLORIMETRIC METHOD FOR THE DETERMINATION OF DISSOLVED OXYGEN

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The determination of dissolved oxygen in water is of importance in the study of such problems as the corrosive effects of water upon metals used in piping systems and the sanitary conditions of streams. It is also an essential part of the test for biochemical oxygen demand. The standard Winkler method (1), modified to prevent interference, is too complicated for the equipment and personnel ordinarily found in small laboratories. A simpler procedure requiring less equipment and fewer standard solutions is also in demand for field work. Several methods described as improvements of the Winkler procedure have been proposed from time to time. The most recent is the modified Miller method (2), which provides for the direct titration of oxygen by a standard solution of ferrous sulfate with methylene blue as an indicator. The involved technic of this method makes it unsuitable for field work or for small laboratories.

As early as 1901, Ramsay and Homfray (3) suggested a colorimetric determination with the use of cuprous chloride, and Rideal (4) proposed the colorimetric estimation of the iodine set free in the Winkler method. A more recent colorimetric estimation of oxygen similar to the original Miller method has been described by Bach (5) who uses phenosafranin as an indicator in place of methylene blue. An accuracy of 0.25 p.p.m. of oxygen is claimed for this technic. McCrumb and Kenny (6) have proposed a method based on the oxidation of manganese, with orthotolidine as an indicator, for the estimation of small quantities of dissolved oxygen in boiler waters. Difficulties with the technic and the necessity of preparing standard solutions have prevented the general adoption of these tests for routine and field work.

Recently, Isaacs (7) described a colorimetric method for the estimation of oxygen with the use of amidol, a photographic developer.

This provides a simple and rapid test apparently satisfactory for field work and for use in laboratories with limited equipment. Doctor Isaacs' kindness in supplying the details of his technic has made possible this study of the practical application of the method to water analyses. The procedure suggested by him is as follows:

> To a sample of water completely filling a glass-stoppered test tube, 150 mm. in length and 14 mm. inside diameter, is added 0.5 ml. of a saturated solution of sodium citrate and 0.13 grams, or 1 ml. of a 13-percent solution of amidol. The stopper is inserted carefully to avoid the entrainment of air, and the contents of the tube are thoroughly mixed by inverting a number of times. At the end of one-half hour, the color produced is read in a Duboscq colorimeter by comparison with a permanent standard. This is equivalent to 14 p.p.m. of oxygen and is prepared from solutions of cobalt chloride and potassium dichromate. If a colorimeter is not available, the standard may be diluted with distilled water to a color comparable to that of the unknown in a graduated test tube of the same dimensions as that which contains the sample. The colors should be viewed across the tubes through a yellow screen. For the tubes a comparator block similar to that used for colorimetric determinations of hydrogen ion concentration is recommended. With concentrations of oxygen of 8.0 p.p.m. or greater, the sensitivity of the test is given as 0.5 p.p.m.; with concentrations of 2.0 p.p.m. or less, the sensitivity is stated to be 0.1 p.p.m.

MODIFIED METHOD

The 14 by 150 mm. test tube has been found awkward to handle and because of its small capacity does not readily permit the collection of representative samples; furthermore, the small cross section of the tubes does not allow a sharp differentiation of color due to small increments of oxygen. As a measure of the oxygen concentration, the dilution of a standard in a graduated tube to a color matching that of an unknown is inconvenient and also inaccurate except in the hands of a person experienced with the technic. The procedure outlined by Isaacs was, therefore, modified to permit the use of glass-stoppered, two-ounce, French square bottles in place of the 14 mm. test tubes. These bottles, which are of 70 ml. capacity, are bulkier than the tubes but are easy to handle, less fragile, and permit the collection of satisfactory samples in accordance with the standard technic.

To simplify the estimation of the oxygen concentration of the sample, a series of permanent color standards equivalent to given amounts of oxygen was developed for use with the two-ounce bottles. The reaction between the amidol and oxygen produces a combina-

tion of colors—a red varying directly with the concentration of oxygen, and a yellow, the intensity of which is not proportional to the concentration of dissolved oxygen. To eliminate the latter, Isaacs suggested that the colors be viewed through a yellow screen.

In the preparation of the permanent standards, varying amounts of a solution of cobalt chloride are used to give the required red color and sufficient quantities of a solution of potassium dichromate are added to each standard to produce a yellow color corresponding to the given concentration of oxygen. This permits direct comparison of the color produced in the sample with the standards and avoids

TABLE 1

Preparation of permanent standards

OXYGEN	COBALT CHLORIDE*	POTASSIUM DICHROMATE†
p.p.m.	*ml.*	*ml.*
0.0	0.3	0.5
1.0	0.6	1.1
2.0	1.5	2.0
4.0	3.8	3.1
6.0	6.8	4.6
8.0	10.4	6.0
10.0	14.4	6.6
12.0	19.5	5.1
14.0	30.0	3.4

The amounts of cobalt chloride and potassium dichromate solutions given are diluted to 50 ml. with distilled water.

* 476 grams of cobalt chloride and 100 ml. of concentrated hydrochloric acid dissolved in water to make one liter. The solution usually requires filtration.

† 2.5 grams of potassium dichromate and 20 ml. of concentrated hydrochloric acid dissolved in distilled water to make one liter.

the use of a yellow screen. The colors can be viewed satisfactorily against the sky, particularly against north light. Direct sunlight is unsatisfactory. In the laboratory they can be observed against a white plate illuminated by a daylight electric bulb. Table 1 gives the quantities of cobalt chloride and potassium dichromate solutions required to produce standards equivalent to specified amounts of oxygen. These quantities are also shown graphically in figure 1, which indicates the relation of the yellow to the red color produced by amidol with varying amounts of oxygen.

In addition to the modification of the standards, the larger sample

necessitated changes in the amount of reagents used. The technic adopted is as follows:

To a sample collected according to standard technic in a two-ounce, French square bottle, is added 1 ml. of sodium citrate solution (750 grams per liter) followed by 2 ml. of amidol solution (130 grams per liter). The sample is well mixed, allowed to stand for thirty minutes to permit full development of color, and compared with standards. Further standing for periods up to two hours causes no apparent change in the color.

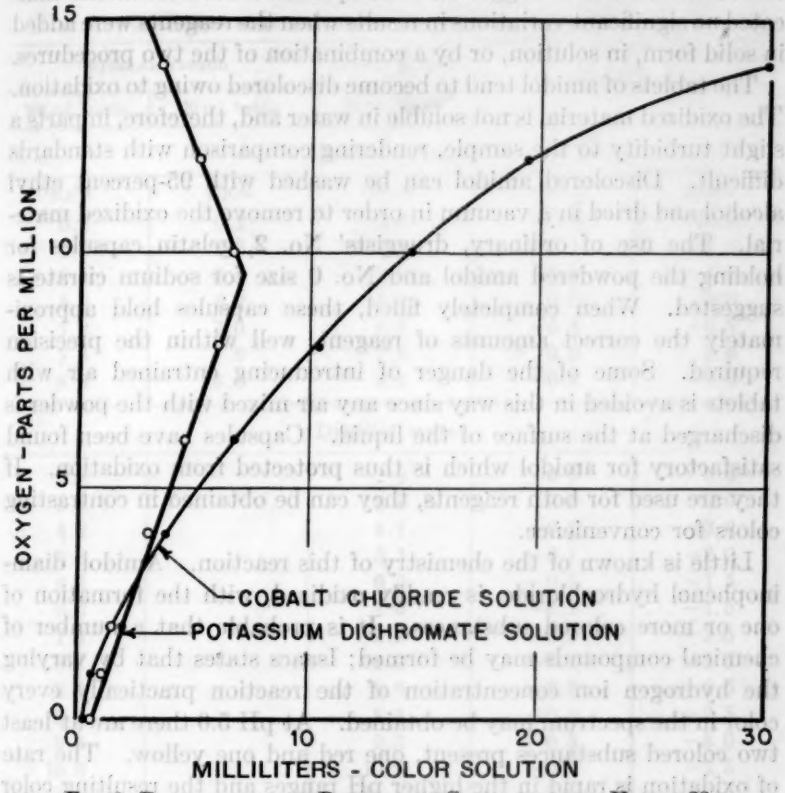

FIG. 1. PREPARATION OF PERMANENT STANDARDS FOR USE AT 30 MILLIMETERS DEPTH

DISCUSSION

For convenience in field determinations, Isaacs recommends the use of tablets of solid amidol and sodium citrate in place of the solutions. A small amount of oxygen is entrained with the tablets and this introduces an error of less than 0.1 p.p.m. However, additional

error due to the formation of a bubble of air under the stopper when the tablets are added is possible. The use of solutions of the reagents eliminates such error and their use has been found satisfactory. The tendency of the amidol solution to adsorb oxygen and thus become discolored prevents its use for accurate determinations unless prepared with oxygen-free water and protected from contact with the air. To avoid these difficulties, the use of solid amidol with a solution of sodium citrate is suggested. Comparative determinations indicated no significant variations in results when the reagents were added in solid form, in solution, or by a combination of the two procedures.

The tablets of amidol tend to become discolored owing to oxidation. The oxidized material is not soluble in water and, therefore, imparts a slight turbidity to the sample, rendering comparison with standards difficult. Discolored amidol can be washed with 95-percent ethyl alcohol and dried in a vacuum in order to remove the oxidized material. The use of ordinary, druggists' No. 2, gelatin capsules for holding the powdered amidol and No. 0 size for sodium citrate is suggested. When completely filled, these capsules hold approximately the correct amounts of reagent, well within the precision required. Some of the danger of introducing entrained air with tablets is avoided in this way since any air mixed with the powder is discharged at the surface of the liquid. Capsules have been found satisfactory for amidol which is thus protected from oxidation. If they are used for both reagents, they can be obtained in contrasting colors for convenience.

Little is known of the chemistry of this reaction. Amidol, diaminophenol hydrochloride, is readily oxidized, with the formation of one or more colored substances. It is probable that a number of chemical compounds may be formed; Isaacs states that by varying the hydrogen ion concentration of the reaction practically every color in the spectrum may be obtained. At pH 5.0 there are at least two colored substances present, one red and one yellow. The rate of oxidation is rapid in the higher pH ranges and the resulting color is much more difficult to reproduce; in the lower ranges, the rate of color production is slower but more uniform. At about pH 5.0 the color reaches a maximum at the end of thirty minutes and remains constant for at least two hours. Sodium citrate is a strong buffer and must be added before the amidol in order that the reaction will take place at pH 5.0. A variation of 25 percent in the quantity of reagents added will not cause a significant change in the pH value.

Exposure to light and variations in temperature of from 0° to 30°C. produced no change in the amount and rate of color development.

COMPARATIVE DETERMINATIONS WITH THE WINKLER METHOD

Dissolved oxygen. To estimate the accuracy of this method as compared with the standard Winkler procedure (8) and also to determine the suitability of the two-ounce, French square bottles for the collection of samples, tap water and distilled water were prepared with varying oxygen concentrations. The oxygen was then determined by the Winkler method with both the two-ounce and the standard 300 ml. bottles, and also by the amidol method with two-ounce

TABLE 2

Comparative determinations of dissolved oxygen

WINKLER METHOD		AMIDOL METHOD	VARIATION	
300 ml. bottle	70 ml. bottle	70 ml. bottle		
Albany tap water				
p.p.m.	*p.p.m.*	*p.p.m.*	*p.p.m.*	*percent*
0.1	0.2	0.2	−0.1	−50.0
1.6	1.6	1.5	−0.1	−7.0
3.4	3.4	3.2	−0.2	−6.0
5.2	5.2	5.2	0.0	0.0
7.2	7.0	6.8	−0.4	−5.5
7.6	7.8	7.6	0.0	0.0
8.8	8.8	8.3	−0.5	−3.0
Distilled water				
2.8		2.8	0.0	0.0
3.3		3.3	0.0	0.0
4.2		4.1	−0.1	−3.0
5.3		5.2	−0.1	−2.0
6.3		6.2	−0.1	−1.5
6.9		7.0	−0.1	−1.5
7.4		7.2	−0.2	−2.5
8.1		8.0	−0.1	−1.5
8.2		8.0	−0.2	−2.5
8.5		8.3	−0.2	−2.5
9.8		9.3	−0.5	−5.0
10.8		10.5	−0.3	−2.5
11.4		11.0	−0.4	−3.5
12.6		12.5	−0.1	−1.0

bottles. The results of these studies are given in table 2. The figures obtained by the colorimetric method are, in general, lower than those by the standard Winkler procedure. The variation in the lower concentrations of oxygen is about 0.1 p.p.m. and in larger concentrations 0.3 p.p.m. Comparative observation by the Winkler method indicated practically no variation in the oxygen determination with the two-ounce bottle and the standard size. In general, the error by the amidol method, as compared with the standard procedure, is about 5 percent, which is considered satisfactory in a colorimetric determination and sufficiently accurate for routine and field work. As in all colorimetric tests, accuracy depends on the precision of interpolation between standards. In these studies, standards spaced 0.5 p.p.m. apart were used for oxygen concentrations below 10 p.p.m., and 2.0 p.p.m. apart above that value, which permitted a reasonable accuracy in estimations of oxygen concentrations. These standards are permanent and have not deteriorated when allowed to stand exposed to variations in light and temperature for two months. As with most colorimetric methods, variations in intensity of light and in the composition of different samples cause the production of slight offshades which may interfere with the comparison against permanent standards. However, these are insignificant so far as the accuracy of the determination is concerned.

Effect of color and turbidity. To determine the effect of color upon the accuracy of this method, samples of tap water of varying oxygen content and with different concentrations of color up to 500 p.p.m. were compared by both the colorimetric and the standard Winkler methods. Owing to its predominantly yellow shade, any color in the sample reacts similarly to the yellow screen proposed by Isaacs, thus intensifying the red of the oxygen-amidol reaction. If the effect of the color is compensated by the use of a comparator block, with the double-bottle method, the amount of oxygen can be read accurately in the presence of color up to 500 p.p.m. A similar study of the interference of turbidity indicated that when compensated by the use of the double-bottled method, turbidity up to 500 p.p.m. has only a negligible effect upon the accuracy of this determination.

Effect of interfering substances. The effect upon this colorimetric method of the substances which interfere with the Winkler procedure was also studied. In general, it was found that oxidizing agents have but little effect on the production of color by amidol, while reducing substances interfere more seriously. Chlorine in amounts

greater than 1.5 p.p.m. affects the color, producing an offshade which interferes with accurate estimation of oxygen. Ferric iron acts similarly when present in amounts greater than 5 p.p.m.

Of the reducing agents, nitrites, sulfites, hydrogen sulfide, and ferrous iron are most often encountered in water and sewage. Nitrites present in amounts greater than 2 p.p.m. interfere seriously with the depth of color produced. Sulfites can be tolerated in concentrations up to 3 p.p.m. and hydrogen sulfide to 5 p.p.m. The extent of these interferences is independent of the concentration of oxygen in the water tested. Table 3 gives the results of these experiments with interfering substances and the limiting values established for each. A modification of the method to remove interference due to nitrites and ferrous iron by the use of the oxidizing action of permanganate decolorized by oxalate was not successful since it was found difficult to adjust the pH value to 5.0 following the action of permanganate in a strongly acid solution. The use of chlorine as an oxidizing agent followed by thiosulfate for dechlorination was also unsuccessful as the presence of thionates or a slight excess of thiosulfate interferes with the production of color and makes accurate readings impossible. It would seem, therefore, that the amidol method is inapplicable in the presence of amounts of these interfering substances greater than the limits indicated.

Results with various types of water, including sea water. No intensive study has been made of the colorimetric method in routine work. Comparative oxygen determinations were done, however, with water samples received for routine chemical examination; very close agreement with the Winkler procedure was obtained. These waters differed widely in solid content, amount of organic matter, and hydrogen ion concentration; it thus appears that these factors do not offer serious interference with the accuracy of the oxygen determination. Phenolphthalein alkalinity greater than 50 p.p.m. was found to prevent production of a color comparable to the standards, probably because of insufficient buffer to maintain a pH value of 5.0.

To determine the suitability of the method for use with sea water and brines, a synthetic sea water was prepared with various oxygen concentrations. No agreement between the oxygen value as shown by the Winkler method and that shown by the colorimetric method was obtained. If this procedure is to be used for the determination of oxygen concentration in sea water or brines, some modification in the technic and special standards will be required.

Use with sewage and for determination of biochemical oxygen demand. The effect of organic matter, particularly sewage solids, was also studied. Raw sewage was oxygenated and diluted in varying proportions with tap water, the oxygen being determined by the modified Winkler and the colorimetric methods with close agreement. Table

TABLE 3

Comparative determinations of dissolved oxygen in the presence of interfering substances

CHLORINE	WINKLER* METHOD	AMIDOL METHOD	FERRIC IRON	WINKLER* METHOD	AMIDOL METHOD	NITRITE NITROGEN	WINKLER* METHOD	AMIDOL METHOD	WINKLER* METHOD	AMIDOL METHOD
p.p.m.	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*
0.5		9.0	0.1	5.2	5.0	0.05	8.0	7.8	4.4	4.3
0.7		9.0	0.3	5.2	5.0	0.1	8.0	7.8	4.4	4.3
1.0		9.0	0.5	5.2	5.0+	0.2	8.1	8.0	4.4	4.3
1.5		9.1+	1.0	5.2	5.0+	0.3	8.2	8.0	4.4	4.5
2.0		9.5++	3.0	5.2	5.0++	0.5	8.2	8.0	4.4	4.3
5.0		10.0++	5.0	5.2	5.0++	0.7	8.1	7.8x	4.4	4.5x
						1.0	8.1	7.8x	4.4	4.7x
						2.0	8.1	8.2x	4.4	4.7xx
						5.0	8.1	8.7xx	4.4	5.0xx

SULFITE	WINKLER* METHOD	AMIDOL METHOD	FERROUS IRON	WINKLER* METHOD	AMIDOL METHOD	HYDROGEN SULFIDE	WINKLER* METHOD	AMIDOL METHOD
p p.m.	*p.p.m*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*
0.0	5.2	5.0	0.0	4.8	5.0	0.0	2.0	2.0
0.5	5.2	5.0	0.1		5.0	1.0	2.0	2.0
1.0	5.2	5.0	0.5	4.8	5.0x	2.0	2.0	2.0
3.0	5.2	4.5°	1.0		5.0x	5.0	2.0	2.0x
5.0	5.2	4.0°°	3.0	4.6	4.5xx			
10.0	5.2	3.0°°°	5.0	4.5	4.0xxx			
			10.0	4.4	3.8xxxx			

* As modified by Theriault (1).

+, brown offshade; x, yellow offshade; and ° red offshade.

4 indicates that organic matter present in sewage does not interfere with the production of color, variations from the standard procedure being within the limits of the precision of the method.

A further study was made of the use of the new method in determinations of biochemical oxygen demand. Dilutions of raw sewage and Imhoff tank effluent were prepared in two-ounce bottles and in

300 ml. bottles. The initial oxygen concentration and the residual after five days' incubation were determined by both the standard and the colorimetric methods. Table 5 gives a typical result for the biochemical oxygen demand computed by the two methods, indicating a reasonable agreement. The use of the two-ounce bottles for this

TABLE 4

Effect of sewage solids and organic matter

RAW SEWAGE DILUTION	DISSOLVED OXYGEN	
	Winkler method	Amidol method
percent	*p.p.m.*	*p.p.m.*
1.0	8.1	7.8
2.0	8.0	7.9
5.0	7.9	7.2
10.0	7.3	7.2
25.0	6.5	6.5
50.0	6.2	6.2
75.0	5.2	5.6
100.0	4.6	4.7

TABLE 5

Determination of biochemical oxygen demand

Imhoff tank effluent

EFFLUENT DILUTION	WINKLER METHOD					AMIDOL METHOD				
	Dissolved oxygen		Depletion		B.O.D.	Dissolved oxygen		Depletion		B.O.D.
	Initial	Final	Actual	Corrected		Initial	Final	Actual	Corrected	
percent	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*
0.0	8.0	8.0	0.0	0.0		7.8	7.7	0.1	0.0	
2.5	8.0	7.5	0.5	0.5	20.0	7.8	7.1	0.7	0.6	24.0
5.0	8.0	6.5	1.5	1.5	30.0	7.8	5.7	2.1	2.0	40.0
10.0	8.0	5.0	3.0	3.0	30.0	7.8	4.6	2.9	2.8	28.0
25.0	7.8	0.0				7.8	0.0			

determination proved satisfactory, introducing no appreciable error and their size simplified the problem of incubation.

SUMMARY

A study of the colorimetric method for the determination of dissolved oxygen with amidol indicates that it should be a valuable

addition to the methods of water and sewage analysis. Much less manipulation, laboratory equipment, and skill are required than with the standard, modified Winkler method. Only two reagents are necessary, neither requiring exactness in preparation, in place of six, one of which requires careful standardization. The use of tablets or capsules for the addition of the reagents in solid form is satisfactory and excludes the necessity of preparing and transporting solutions. To prevent error due to entrained air, the use of a solution of sodium citrate instead of the solid is recommended, the amidol being added in solid form. Modifications of the method to permit the substitution of two-ounce, French square bottles for the test tubes suggested in the original method have proved satisfactory. Permanent standards are described which give a satisfactory estimation of the oxygen concentration and are readily prepared.

The interfering effect of certain oxidizing and reducing substances found in water and sewage may preclude the use of the method when they are present in amounts greater than the limiting values. Color, turbidity, and organic matter do not affect the accuracy of the method and it may be used for determinations of biochemical oxygen demand and for oxygen in highly-colored or turbid waters. Presumably, the test will not be as precise a measure of the dissolved oxygen as is the standard Winkler method. It has been found to be accurate, however, within 0.1 p.p.m. with low concentrations of oxygen and to within 0.3 p.p.m. with larger concentrations, the error, in general, being no greater than 5 percent in comparative tests with the standard Winkler method.

The method has the inherent difficulties of all colorimetric determinations in which permanent standards are used. The ease and rapidity with which it can be carried out will undoubtedly render it valuable for small water works and sewage plant laboratories and for field work. The ultimate value of the method depends on the success with which it is used with various types of water and sewage and under varying conditions and by many different workers.

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PROGRESS REPORT OF COMMITTEE ON TENTATIVE METHODS FOR TESTING ZEOLITES

There are no laboratory tests which indicate as reliably as experience, the quality of zeolite. Nevertheless, there are available means of comparing the quality of various zeolites, which may be determined by simple laboratory tests, and it is these which we are interested in developing and perfecting. The tests include:

1. Grain size and percentage of fines.
2. Weight per cubic foot of zeolite as received.
3. Resistance to attrition loss.
4. Ratio of alumina to silica (this test is especially applicable to synthetic zeolite).
5. Exchange value and percentage of expansion on back washing.

Collection of sample. The importance of a truly representative sample cannot be over emphasized. If material is shipped in bags, barrels, or drums, a representative sample shall be collected by taking portions from at least 5 percent of the containers scattered throughout the entire shipment. Mix portions thoroughly and quarter down to about 15 pounds. If the zeolite is already in place in the softener, accurate sampling is particularly difficult, especially if the softener has been backwashed. A representative sample from the entire depth of the bed should be taken. This involves using a sampling tube or digging down into the bed through its entire depth. If the softener is a large one, samples should of course be taken from different portions of the bed.

I. GRAIN SIZE AND PERCENTAGE OF FINES

Before proceeding with the screen test, zeolite should be air dried at room temperature until the granules are dry enough to flow freely. Two hundred grams of the synthetic, or 500 grams of greensand, or other heavy zeolite is to be used.

Testing sieves. The tests are to be made with 8-inch diameter sieves having the U. S. Bureau of Standards Screen Scale openings as follows:

Sieve Number	*Sieve Openings in Millimeters*
19	2.38
10	2.00
16	1.19
20	0.84
30	0.59
40	0.42
50	0.297
60	0.250

Degree of shaking. When using machine shaking with Ro-Tap Testing Sieve Shaker (manufactured by W. S. Tyler Co., Cleveland, Ohio) operate shaking machine for 5 minutes (about 130 taps per minute are obtained in this standard machine) using the entire set of 8 sieves at one time.

When manual shaking is used, rock the nest of sieves containing sample, back and forth over a stick so that the bottom pan is about 1 inch above table. Rock at the rate of 150 bumps per minute (75 on each side) bumping the entire nest against the table in this manner for 5 minutes.

After the shaking is completed by either of the above methods, the material retained on each screen is weighed and the screen analysis calculated accordingly. Report results in percent retained on each consecutive screen mesh.

Commercial grades of greensand are usually graded so that all of it passes a 16 mesh screen, but only a small percentage passes a 60 mesh.

Synthetic zeolites all usually pass on 8 mesh screen, but very little passes a 50 mesh.

If it is desired to know the effective size and uniformity coefficient, proceed as outlined for filter sand, Water Works Practice, page 634.

II. WEIGHT PER CUBIC FOOT OF ZEOLITE AS RECEIVED

Since capacity of zeolite is figured on the cubic foot basis and the zeolite is shipped on a weight basis, it is desirable to know the weight per cubic foot of the material shipped which will occupy one cubic foot after being backwashed at a rate sufficient to give a 50 percent expansion of the mineral, and completely drained.

Procedure. Weigh out a sufficient amount of zeolite to make a bed about 30 inches deep. Place in a calibrated tube about 4 inches in diameter and about 5 feet long. Back wash sufficiently to give a

50 percent expansion of the mineral for 5 minutes, being careful not to wash out any of the zeolite. Drain slowly but completely and measure volume of drained bed in calibrated tube.

$$\frac{\text{Weight of material placed in tube}}{\text{Cubic footage space occupied after backwashing}} = \text{Weight per cubic foot of material as received}$$

As a matter of information, it may also be advisable to know the moisture content of the sample.

III. RESISTANCE TO ATTRITION LOSS AND AGGRESSIVE ATTACK

There is urgent need for tests that will show whether zeolite will withstand attrition and aggressive attack and indicate whether it will give long years of operating service.

A simple test for detecting poorly processed, or inferior soft grades of zeolite, may be made as follows:

A definite quantity of regenerated zeolite is placed with distilled water in a cylindrical glass tube or bottle (a 4 oz. rubber stoppered oil sample bottle about 1½ inch diameter by 6¼ inch overall, is convenient) mounted on a rotating wheel with bottom of bottles about 1 inch from center. After revolving for one hour at 17 r.p.m. the supernatant liquid is poured off and its turbidity determined by a candle turbidimeter. This operation is repeated until a constant or no further turbidity can be seen in the distilled water.

Hungerford & Terry[1] suggest the following method for measuring Attrition Loss.

The method of determining the resistance to attrition loss of zeolite is a measure in parts per million turbidity of the grains resistance to attrition.

Apparatus:

1. Motor, carriage, and ball mill. Motor to be geared to turn mill 65 r.p.m.
2. Crushing charge of 200 grams of hard smooth pebbles of approximately 5.66 mm. diameter.
3. One Jackson candle turbidimeter.
4. One 250 cc. graduated cylinder.
5. One 500 cc. graduated cylinder.
6. Balance for weighing charge.

[1] Zeolite Manufacturers, Clayton, N. J.

Method of determination:

1. Take sample as used and dry to constant weight at not more than 100°F.

2. Pour into a 250 cc. graduate, 150 cc. of turbidity free water. To this add enough dry sample to bring the water level to 210 cc. This then gives 60 cc. of actual volume of sample to be tested (neglecting internal voids).

3. Put this 60 cc. of sample, 200 grams of pebbles, and a total of 400 cc. of turbidity free water into the ball mill. Attach head, place in carriage, and give 125 revolutions. Drain the contents completely, (sample, pebbles, and water) into a suitable container and wash the sample and pebbles thoroughly, separating them.

4. Dry the sample and pebbles to constant weight at not more than 100°F. A more intense heat may effect the hardness. Pour 100 cc. of turbidity free water into the 250 cc. graduate. Add enough of the dried sample to raise the water level to 140 cc. This gives 40 cc. of actual volume of the dried sample to complete the test (neglecting internal voids). Put this 40 cc. of sample, 200 grams of pebbles and a total of 400 cc. of turbidity free water into the ball mill. Give this a milling of 125 revolutions. Drain the entire contents into a suitable container (by passing the contents through a #10 sieve the pebbles can be separated from the sample). Wash the ball mill thoroughly into this same container. From this container, decant the washings, thoroughly washing the sample, into a 2 liter container. Make volume up to 2 liters with turbidity free water. Determine the turbidity of this water on the Jackson candle turbidimeter. This gives the hardness in parts per million turbidity. To obtain the hardness value, read the values from a prepared chart, or obtain it from the formula:

$$\frac{10{,}000}{\text{Turbidity, ppm.}} = \text{Hardness.}$$

The C. F. Burgess Laboratories, Inc.,[2] suggest the following method of measuring attrition loss: Place a bed of 15 cm. deep of zeolite in a 2-inch diameter glass tube (measured tapped down under water). Add water to make a total depth of bed and water of 31 cm. Use only distilled water throughout this test. Bubble air through 8 mm. diameter glass tube centrally located in a stopper, at a rate of 750 cc.

[2] Zeolite Manufacturers, Madison, Wisconsin.

per minute for three hours, thus churning the zeolite in the water. Wash repeatedly through 80 mesh screen. Make washings to 1 liter. Determine dry material loss by evaporation, drying at 105°C. for eight hours or more and weighing. Knowing the moisture and total weight of the zeolite used, express result as percent loss. Repeat this test ten times in order to establish a definite trend.

It is claimed that this method more nearly simulates actual service conditions than the others. Also it is to be noted that the turbidity produced is measured gravimetrically instead of being read in a turbidimeter, thus eliminating possible errors due to particle size.

The Permutit Company,[3] suggests the following method for measuring Resistance to Aggressive Attack, and claims that the results from this accelerated test are a reliable indicator of the service which may be expected from material when used in practical operation.

Solutions:

A. Dissolve 192 grams glacial acetic acid + 13.6 grams crystallized sodium acetate ($NaC_2H_3O_2 \cdot 3H_2O$) per liter of distilled water. This gives a strongly buffered solution of pH 3.2.

B. Five percent solution of C.P. NaCl.

Procedure. After thorough regeneration and rinsing, air dry the material and screen out about 15 grams to 30–40 mesh (U.S. Bureau of Standards). Determine moisture content of this air dried material on duplicate samples by the Standard Method.

Now weigh out duplicate samples of this air dried 30–40 mesh material, each sample weighing exactly 1.0 gram net (calculated on dry basis after making allowance for moisture content). Place each sample in a 4 ounce rubber stoppered oil sample bottle (about 1½ inch diameter by 6¼ inch overall), and fill each bottle completely (about 120 cc.) with Acid solution A. Then stopper the bottles and mount on rotating wheel with bottom of bottles about 1 inch from center and rotate for 2 hours at 14 r.p.m. at room temperature 20–25°C.

Decant supernatant liquid; rinse the residual material thoroughly with distilled water; transfer to weighing bottles and dry at 105°C. for at least 3 hours; reweigh after cooling in desiccator and calculate percent loss of weight on the 1.0 gram samples (dry basis) as percent weight loss due to aggressive attack.

IV. RATIO OF ALUMINA TO SILICA (APPLICABLE TO SYNTHETIC ZEOLITE)

Generally speaking, other things being equal and within certain limits, the lower the ratio of alumina to silica, the harder the zeolite

[3] Zeolite Manufacturers, 330 West 42nd St., New York, N. Y.

and the lower the softening capacity. The ratios are expressed as moles $Na_2O:Al_2O_3:SiO_2$.

Determination of silica:

Preparation of sample. The sample of zeolite to be tested should be washed in strong salt solution (about 50 percent saturation) and then washed with distilled water, and air dried. This sample is then thoroughly ground in a mortar. 1 gram of sample is taken for moisture determination by ignition loss.

Procedure: Take ½ gram of sample, moisten with water. Add 20 ml. 6 N HCl, and dry to dryness in a platinum, fused silica, or sillimanite dish. Repeat this operation two or three times. After sample has been so treated and dried, bake in oven at 120 to 130°C. for one hour. Moisten baked residue with HCl and take up with distilled water, heat to boiling, and filter. Wash thoroughly and dry residue, blast one hour, or to constant weight, and weigh.

$$\frac{\text{Weight of silica}}{\text{Weight of dry sample}} \times (100 - \text{percent moisture}) = \text{percent silica } (SiO_2) \text{ on moist sample.}$$

Determination of alumina. Boil filtrate from above to approximately 100 cc. precipitate with ammonium hydrate, boil, and stir for 10 minutes, filter, wash, and blast for 30 minutes in platinum crucible. Weigh as alumina (Al_2O_3) unless appearance of precipitate shows iron. If iron is present weigh as R_2O_3, determine iron and subtract from R_2O_3.

Determination of sodium. Sum of percentages of silica (SiO_2) plus alumina (Al_2O_3) and iron oxide (Fe_2O_3) subtracted from 100 = percent Sodium oxide (Na_2O), or sodium may be determined directly by any standard method of analysis.

Low silica in water to be softened permits extraction of silica from zeolite with consequent failure of zeolite. Water to be softened through zeolite should have at least 8 p.p.m. silica.

V. EXCHANGE VALUE

In this determination, operating exchange, or capacity value is meant, and not total exchange, because in practice it is not customary to operate zeolite softeners until they are completely exhausted. They are usually operated until they fail to produce practically zero hardness water, i.e., until 1 ml. of standard soap solution (Standard Methods of Water Analysis, 1933) in a 50 ml. sample fails to produce

a lather. The exchange value is determined by constructing a small unit filled with a measured volume of zeolite. The volume is determined after the zeolite has been backwashed at a rate sufficient to give 50 percent expansion of mineral, and then completely drained. (When backwashing, the percentage of expansion should be recorded.) The bed shall be 2 inches in diameter and the depth of zeolite 24 inches. The water shall be passed through it downwardly at a flow rate of 2 gallons per square foot per minute. A 4 percent brine solution shall be used, and approximately 0.5 pound of salt shall be allowed per 1000 grains of hardness removed. In other words, in testing synthetic zeolites, it will be assumed that each cubic foot will remove 10,000 grains of hardness and the salt charge figured accordingly. On the other hand, greensand will be assumed to remove 2800 grains per cubic foot.

If the brine charge is originally calculated on the basis of 10,000 grains capacity for synthetic zeolites and 2800 grains for greensand (both at 0.5 pound salt per 1000 grains of hardness removed), and it is found that the exchange capacities are materially different from what was assumed, the brine charge should be changed so as to finally reach equilibrium with a salt consumption of 0.5 pound per 1000 grains capacity.

Before brining, the bed should be backwashed and the water drained to the top of the zeolite bed. The brine is now introduced carefully, and passed through the bed in approximately 15 minutes. When the level of the brine has dropped to the top of the zeolite bed, hard water is introduced carefully so as not to seriously disturb the surface of the zeolite bed. The washing with water is continued at the brining rate of flow until soft water is obtained, whereupon the flow should be increased to correspond to the two gallon softening rate.

The hard water used should preferably be prepared (CaCl and $MgSO_4$ are suggested). For synthetic zeolite it is convenient to use water with a hardness of 400 p.p.m., two-thirds of the hardness being calcium hardness and one-third magnesium. For greensand, cut hardness of raw water to about 170 p.p.m.

Natural waters may be used but they must be clear, free from iron and manganese, and not contain excessive amounts of sodium or magnesium salts.

Three preliminary runs should be made preceding the test in order to make sure that any caustic used in processing and making the

zeolite has been washed out. It is preferable to make and average the results of five test runs. Knowing (a) the volume of mineral; (b) the quantity of water softened; (c) the hardness of the water softened, the exchange value can be readily computed.

In addition to the references cited, the committe is indebted to Mr. A. S. Behrman of the International Filter Company, 59 E. Van Buren St., Chicago, Ill., manufacturers of Crystallite, the Arizona Minerals Corporation, Yuma, Arizona, and the Refinite Company, Omaha, Nebraska, for valuable suggestions and criticisms.

CHARLES P. HOOVER, *Chairman*,
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ACID MINE DRAINAGE CONTROL ON UPPER OHIO RIVER TRIBUTARIES

By E. S. Tisdale and E. W. Lyon

(*State Health Department, Charleston, W. Va.*)

Conservation of the water resources of the United States is now receiving a great deal of study and consideration by the National Resources Board and by the several state planning boards.

Acid mine waste pollution in the bituminous coal mining areas of Pennsylvania, Ohio, West Virginia and Kentucky is the outstanding industrial waste pollution on the Ohio River watershed and through the agency of the Inter-State Stream Conservation Agreement of 1924, these states are endeavoring to develop control measures in this field as they did in successfully controlling harmful phenol wastes pollution. Acid mine wastes pollution exacts tremendous economic damage yearly in each state and is a menace to public health through affecting detrimentally public water supplies.

A LARGE SCALE EXPERIMENT IN MINE SEALING

A large scale experiment of sealing abandoned coal mines has been carried on for over a year now by the U. S. Public Health Service and the health departments of Pennsylvania, Ohio and West Virginia. The remedial program of "air sealing" these abandoned mining areas has been based upon the laboratory research work of the U. S. Bureau of Mines under the supervision of Dr. R. R. Sayers, W. P. Yant and W. D. Leitch, extending over a period of years, and upon the full scale demonstrations in western Pennsylvania by the State Health Department of Pennsylvania under W. L. Stevenson's direction. In the practical application of the air sealing principles during the past year, we have been shutting down nature's countless numbers of sulphuric acid manufacturing plants, producing mine acid through the oxidation of gob and pyrites in the subterranean caverns of the bituminous mining regions of Pennsylvania, Ohio and West Virginia. Our full scale experiments in West Virginia, 215 of them, have proven conclusively that sealing abandoned mines is a *decided success* in

reducing acid pollution of streams and the program should be carried to completion in all the states.

PROGRESS REPORT AT AMERICAN WATER WORKS ASSOCIATION SECTION MEETING

Last August, 1934, at Wheeling, West Virginia, before the Central States Section of the American Water Works Association, a progress report was made upon the Federal mine sealing program of the previous winter showing the coördinated program of Pennsylvania, Ohio and West Virginia under the direction of Chief Engineer, R. E. Tarbett of the U. S. Public Health Service, outlining the organization and accomplishments of these states in sealing abandoned mines to reduce acid mine waste pollution. It was too early then to do anything more than show a tendency, but at Wheeling, it was definitely reported by the writers that favorable reductions of acid mine water pollution were being noticed in Ohio, in Pennsylvania and in West Virginia from air sealing abandoned mines. Reference was made to the simple chemical principle, which is the keynote of this entire undertaking, namely, the exclusion of the oxygen in the air from coming in contact with the pyrites and marcasites in the old mines, thus preventing the formation of ferrous sulphate and sulphuric acid. In the early experimental work of the U. S. Bureau of Mines, rain water was passed over sulphur balls found in the coal, but no air was allowed to come in contact with them. *No acid was formed.* Next, these same experiments were repeated, but instead of water, moist air was passed over the sulphur balls. *Acid was quickly produced.* In sealing the mine mouth, by a concrete or masonry brattice, a trap is used to permit free drainage of water but to prevent air from getting back into the mine. All other openings and any breaks which have taken place along the crop line, or on the mountain side have to be filled with dirt so that the mine is completely sealed from air currents. Experience during the winter of 1933–1934 showed the vital necessity of repair and maintenance work in order to get favorable acid reduction.

WEST VIRGINIA PROGRAM ON MINE SEALING FROM APRIL, 1934 TO APRIL, 1935

The State Water Commission of West Virginia, created by statute in 1929, to deal with stream pollution control work, has been the agency which, together with the State Health Department and the

State Emergency Relief Administration, has enabled West Virginia to continue the mine sealing program without interruption for 15 months and secure information, which indicates whether or not we are proceeding along remedial lines which will ultimately lead to success in controlling this greatest of stream pollution menaces in the Ohio River Basin. The acid pollution in West Virginia coming from all types of coal mines is known to be over three and one-half million pounds of acid per day.

A decentralized supervisory organization, directed by the State Health Department, and keyed to the County Civil Works Administration, has been functioning and a total of $129,487.00 was spent in the first three months period. Since then $84,830.00 has been spent in carrying forward the work of construction, field surveys, collection and analysis of water samples, under a supervisory organization of seven trained mining engineers of long experience in the West Virginia coal fields. Maintenance, repairs and construction work has gone forward in 19 counties and throughout the entire period of Civil Works Administration and Emergency Relief Administration, that is, for the last fifteen months, heartiest coöperation has been received from Director, C. L. Allen, Work Relief Division, Emergency Relief Administration and his district engineers in the 19 counties. Likewise, the coal operators, the surface owners have generously donated material and a vital interest has been displayed by sportsmen and the public generally in the mine sealing activities.

Work has been started on 277 mines, involving the closing of over 4,500 openings, in these 19 counties. Two hundred and fifteen (215) mines have been completely closed and maintained in a sealed condition so that a study has been carried through on these mines to ascertain the results being secured by way of acid reduction. In all, six hundred and eleven (611) mines have been inspected and 2,500 water samples collected and analyzed by a graduate chemist at West Virginia University working under the supervision of Professor L. V. Carpenter, head of the Sanitary Engineering Department there.

Up to March 1, 1935, $214,317.00 had been expended and 63,555 six man hour days of employment furnished to stranded coal miners and other unemployed laborers. Exceedingly valuable salvage, maintenance, completion of unfinished mines and new mine sealing has been accomplished under the Emergency Relief Administration program of the past year, but the work has necessarily proceeded at a much slower rate of progress during the past twelve months with an

average of 150 men working daily as compared with nearly 1,000 men at work daily when the program started in the winter of 1934.

Investigations already made show that there are from 400 to 500 additional mines requiring attention, on which work has not yet been started. These must be sealed before any marked stream conservation affecting the main Ohio River can be expected. Already water works officials and sportsmen are noticing a real improvement on some of the tributary streams of the Ohio in northern and southern West Virginia.

It is estimated that the remaining work will furnish 120,000 six hour man days of employment to complete the major sealing operations. Thereafter, a small force will be required to take care of maintenance and new breaks.

THE ECONOMIC COST OF ACID MINE POLLUTION IN WEST VIRGINIA

The West Virginia Planning Board has taken cognizance of work and studies on mine acid pollution and at their request, studies were made to ascertain the magnitude of the drainage from acid mine wastes in West Virginia.

Previous official reports by four state health departments, Pennsylvania, Ohio, Kentucky and West Virginia, had conclusively shown the extension of the acid zone of water caused principally by mine drainage, further and further down the Ohio River each year, menacing public health through affecting detrimentally public water supplies taken from the river. Mention was made of the economic damage done by acid mine water under six headings in the report filed with the U. S. Public Health Service late in the year 1933:

1. Increased cost of construction and operation of water works was noted.

2. Damage was great to locks and dams and vessels in inter-state commerce along the navigable streams.

3. Industrial plants and railroads were forced to spend large sums of money to make the water satisfactory for boiler and steam raising purposes.

4. Serious deterioration of drainage lines, culverts and bridges along state and Federal highways has been reported.

5. Harm was done to the recreational use of streams for purposes of camping, swimming and fishing.

6. Agricultural lands and stock watering were detrimentally affected.

To prove to the State Planning Board the fact that it would be real economy to complete the mine sealing program in West Virginia, certain cost data bearing on the above items were assembled to show the damage resulting from acid mine drainage.

The State Highway Department has just completed detailed investigations in 55 counties in the state in conjunction with the University of West Virginia. These indicate that the present and potential expense to culverts on the primary and secondary road systems is $500,000.00 annually, divided between the deterioration of concrete culverts and the added expense of installing concrete where lower cost metal culverts might otherwise be used.

One railroad system in southern West Virginia, which pays careful attention to boiler water preparation, has estimated that $25,000.00 annually would be saved due to reduction of chemicals, required for water treatment, if acid mine drainage was held to a minimum. Higher costs are to be expected in water treatment for railroads in northern West Virginia because of the higher concentration of acid mine drainage there.

Water plant superintendents and consumers at Fairmont, Morgantown and Wheeling, reported that acid water causes an expenditure of $50,000.00 annually in these three cities for additional chemicals and treatment of water and increased soap consumption costs occasioned by the hardness and acid content of river water.

Startlingly high economic costs are reported by Trax of McKeesport for the Monongahela River and Drake of Pittsburgh for the Allegheny River. Edward C. Trax, who for twenty-five years has worked in the field of water treatment with river waters polluted by mine drainage, estimated the cost to the industries and water plants in the fifty mile stretch along the Monongahela between the West Virginia line and McKeesport, as follows:

Public water supplies, 33 mil. gal. day @ $12.00	$396.00
Industrial softening, 25 mil. gal. day @ 12.00	300.00
Cooling water, 500 mil. gal. day @ 3.00	1,500.00
Cost daily	$2,196.00

This gives the astounding total of $801,000.00 per year as costs which could be largely eliminated if the acid mine wastes pollution on the Monongahela River could be materially reduced.

Chester F. Drake, Superintendent at the Aspinwall filtration plant for Pittsburgh, drawing water from the Allegheny River, reports

greatly increased costs of water treatment, reaching an all time high, of three million pounds of soda ash for 1934 to neutralize the mineral acidity in the river water prior to filtration.

The recreational assets of many of West Virginia's beautiful streams have been reduced in a major way by acid mine drainage. It is difficult to calculate this damage to fishing and camping, as well as the agricultural damage in terms of dollars and cents.

However, summing up the whole question, it may be conservatively estimated that West Virginia suffers a loss of approximately $1,000,000.00 annually on account of acid mine drainage. It appears highly reasonable to proceed with a known practical remedial measure.

CHARTS SHOW ACCOMPLISHMENTS DURING 1934

In order to find out the magnitude of the task and measure the progress made by excluding oxygen from the underground areas, from which coal has been removed, it was necessary to have detailed information on the flow and acidity of the acid water coming from all active, inactive and abandoned mines. One of the biggest factors assisting the West Virginia Mine Sealing program was the fact that trained mining engineers with decades of experience in all sections of West Virginia, who carried in their minds a picture of the minable coal seams, were in charge of engineering work. They built up graphically the acid load on every watershed in West Virginia and plotted from field sketches, on topographic sheets, the mine areas sealed and worked upon, as the total flows and acidities of the thousands of mine waters were received from the supervisors of the four districts. These data covering the first fifteen months of work, when compiled by C. L. Chapman, in charge of this phase of the engineering work, and translated into pie-plate charts and simple curves show astounding totals and trends of acid reduction.

In West Virginia, preliminary surveys made by the mine sealing organization and independently checked through other detailed and authoritative studies on mine acid water flows from all the mined out areas in West Virginia, show that there are discharged into the streams of the State, each day three and one half million pounds of mine acid.

As the chart shows, 54 percent, the major portion, comes from abandoned mines; 15 percent from marginal or inactive mines and 31 percent from active mines, many of which have worked out areas in

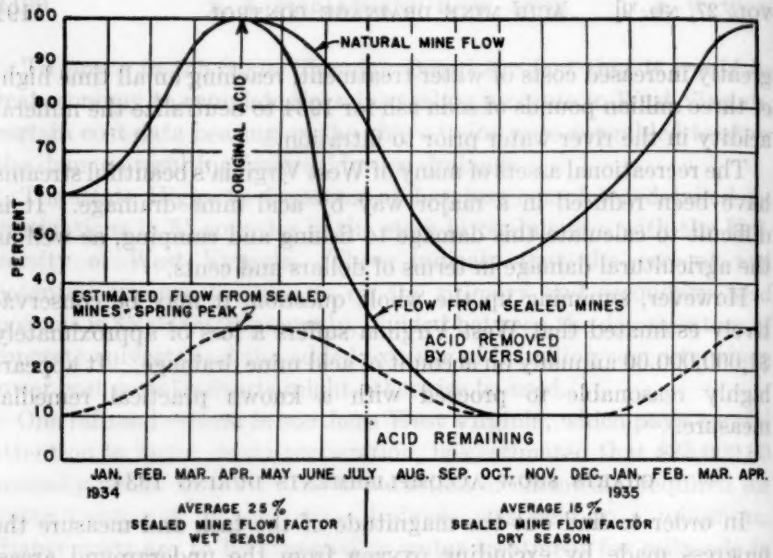


FIG. 1. CURVE SHOWING MINE FLOW OF WATER BY MONTHS IN PERCENT OF MAXIMUM FLOW FOR 1934, WEST VIRGINIA

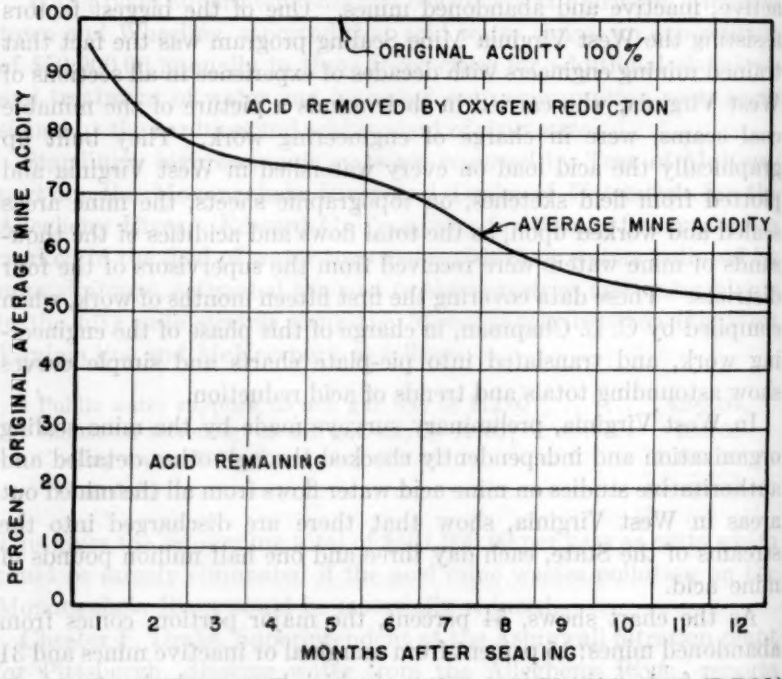


FIG. 2. CURVE SHOWING REDUCTION OF AVERAGE MINE ACIDITY (P.P.M.) PER MINE AFTER SEALING—118 MINES

them, which might be sealed to the advantage of both the owner and the state. In all, it is estimated that 66 percent of the total acid load can be eliminated by sealing. The major part of the remainder would be largely neutralized by the natural alkalinity of the streams, where there is sufficient dilution.

In the older bituminous fields, the aggregate amount of acid discharged from abandoned mines is a major part of all the acid mine wastes discharged to streams and menacing public water supplies.

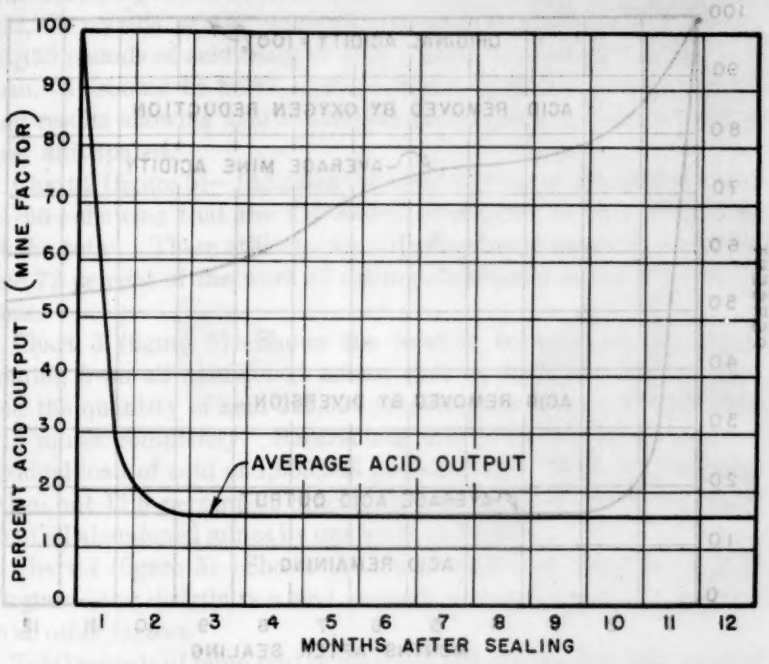


FIG. 3. CURVE SHOWING REDUCTION IN AVERAGE ACID OUTPUT IN PERCENT OF POUNDS AFTER SEALING 118 MINES. EACH MINE ORIGINAL ACID TAKEN AS 100 PERCENT

It has been found that there are two main factors in the acid reduction program, the *quantity-of-water* factor, and the *quality-of-water* or relative acidity factor. The first one is determined in the field by weiring the water as it flows from the abandoned mine, the second is obtained in the chemical laboratory after careful analysis of the water samples from mine openings. The laboratory supervision of the water analysis work by L. V. Carpenter of West Virginia University, who has been studying and experimenting with mine acid waters for several years, has been of vital assistance to the program.

The relation between quantities of water flowing from unsealed mines, compared to sealed ones indicates in figure 1 clearly that about 75 percent of the water formerly entering the mines through surface breaks and other openings is now shunted directly into the streams, not entering the mines. Here then we have a substantial lessening of the quantity factor.

The reduction of average mine acidity (p.p.m.) per month is shown

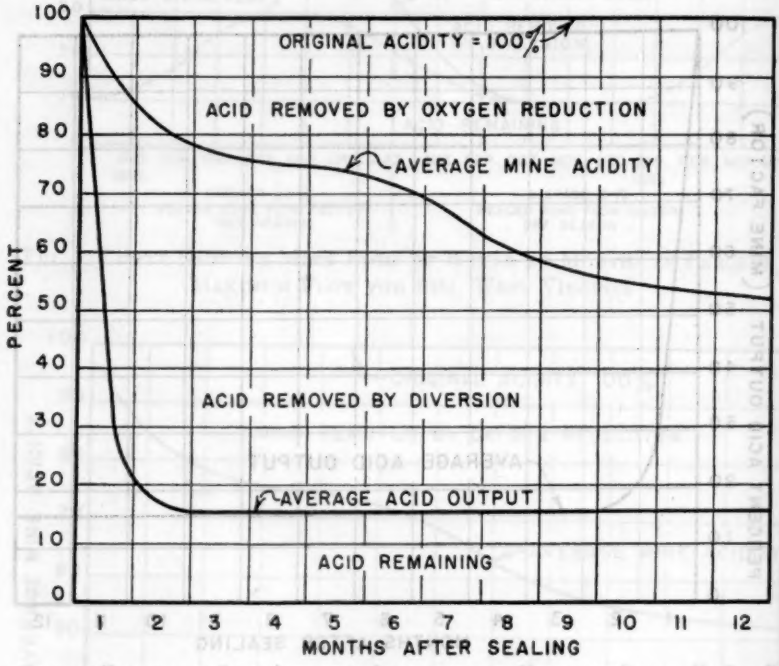


FIG. 4. CURVE SHOWING REDUCTION IN MINE ACIDITY AND ACID OUTPUT FOR 118 MINES AFTER SEALING. ORIGINAL ACID AT TIME OF SEALING—EACH MINE TAKEN AS 100 PERCENT

in figure 2. It is a composite made up from water tests on samples collected from 118 sealed mines, which had been closed for nine months.

The reduction in average acid out-put in percent of pounds is given in figure 3 and is a combination of the quantity and quality factors, depicted in the two previous graphs.

Two curves of reduction are shown in figure 4, the mine acidity

curve dropping slowly as the months pass, the acid out-put showing a sharp drop due to the big reduction in water flow.

FOUR-PIE-PLATE-CHARTS SHOW ACID LOAD BEFORE AND AFTER SEALING

Chart 1 (figure 5)—Shows the accomplishments of sealing 215 mines with its resultant effect, eliminating nearly 80 percent of the acid drainage. Before sealing, the acid load from these 215 mines was 285,950 pounds of acid daily. After sealing for nine months 222,525 pounds or 111 tones of acid had been eliminated, leaving 63,425 pounds of acid daily or 22.2 percent only of the original acid load. It should be borne in mind that only 9 months have passed and results showing acid reductions are showing up sooner than at first anticipated.

Chart 2 (figure 5)—Indicates the total number of abandoned mines —766—showing that the 215 sealed correspond to only 28 percent of the total. There still remain 551 abandoned mines to be sealed and 72 percent of the work of sealing abandoned mines is yet to be done.

Chart 3 (figure 5)—Shows the relation between the total acid coming from all abandoned mines, that is, 1,877,300 pounds daily and the quantity of acid 222,525 pounds daily taken out by sealing 215 mines completely. Subtracting one from the other shows a residual load of acid of 1,660,985 pounds daily. Thus we have only taken out 11.8 percent or practically one-eighth of the acid coming from all abandoned mines by our work up to date.

Chart 4 (figure 5)—Shows the entire acid load analysis for West Virginia—the distribution and present accomplishments in relation to all other factors.

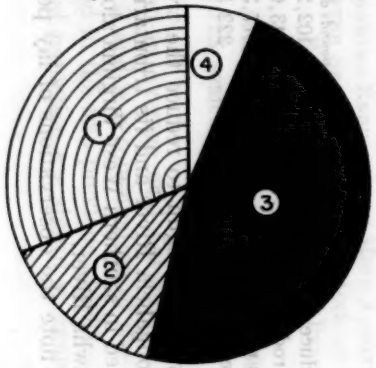
Total pounds of mine acid in State—3,523,500 pounds daily coming from 1,440 mines.

	pounds daily	*percent*
1. Active mines produce	1,102,205	31.0
2. Marginal mines produce	543,915	15.5
3. Abandoned mines produce	1,877,300	53.5
4. Total acid removed	222,525	6.3

This indicates that we have begun to reduce the tremendous acid pollution of the Monongahela River and its tributaries. The same trend has been observed in southern West Virginia along the tributaries of the Great Kanawha River.

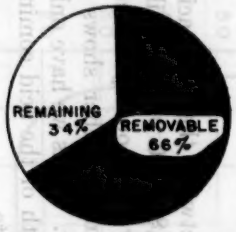
It is interesting to note the observations of lay persons, some of

CHART 4
DISTRIBUTION OF ACID
AND TOTAL POUNDS MINE ACID IN STATE
3,523,500 LB. DAILY 1440 MINES



ACID FROM
1-ACTIVE MINES 1,102,285 POUNDS DAILY- -31.0 %
2-MARGINAL MINES 543,915 POUNDS DAILY - -15.5%
3-ABANDONED MINES 1,877,300 POUNDS DAILY- 53.5%
4-PERCENT TOTAL ACID REMOVED 222,525 POUNDS DAILY 6.3 %

TOTAL ESTIMATED ACID REMOVABLE

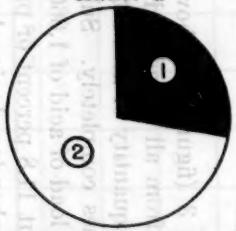


ESTIMATED PERCENT OF TOTAL ACID REMOVABLE INCLUDING ESTIMATED PART OF MARGINAL MINES & ESTIMATED AMOUNT OF PARTIAL SEALING PROJECTS IN ACTIVE MINES ADDED TO ABANDONED MINES.

CHART 1
ACCOMPLISHMENT
IMPROVEMENT 215 MINES SEALED

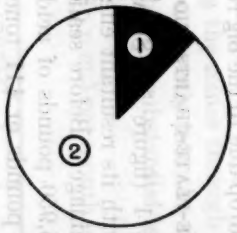
TOTAL ORIGINAL ACID 285,950 POUNDS DAILY
1-ACID REMOVED-222,525 LB. DAILY-77.8 %
2-ACID REMAINING-63,425 LB. DAILY- 22.2 %
RATIO OF DAILY IMPROVEMENT ON 215 MINES SEALED FOR AVERAGE OF 9 MONTHS

CHART 2



TOTAL ABANDONED MINES 766
RATIO OF ABANDONED MINES SEALED TO TOTAL ABANDONED MINES
1-MINES SEALED 28.0%- 215
2-MINES UNSEALED 72.0%-551

CHART 3



TOTAL ACID ABON. MINES 1,877,300 LB. DAILY
1-ACID REMOVED-222,525 LB. DAILY 12 %
2-ACID REMAINING-1,660,980 LB. DAILY 88%
ACCOMPLISHMENT BASED ON A STUDY OF 118 SEALED MINES ALL OVER W. VIRGINIA

FIG. 5. RESULTS OF SEALING ABANDONED COAL MINES IN WEST VIRGINIA. INFORMATION AS OF APRIL 1, 1935

whom were quite skeptical of mine sealing, when the program was started in January, 1934. Superintendents of filtration and water works officials at city water plants such as Fairmont, Belington, Philippi, and Grafton along the Tygart Valley River, state that they have already observed a material improvement with respect to lessened acidity of the Tygart Valley River water. This is characterized by a disappearance of the brownish coloration of the rocks in the river; and by increased length of life of boiler tubes in pumping stations, which have to pump untreated river water. It is reliably reported also by fishermen that aquatic life is starting back in streams formerly devoid of fish life. The State Director of Conservation is likewise receiving news of improved fishing in certain streams, which for the past few years have been detrimentally affected by acid mine drainage prior to the sealing program. It is interesting to receive these independent observations by those who watch the aquatic life in the streams for they constitute evidence to corroborate the chemical tests on the mine water from sealed openings, which tests show a definite lessening of the acid load.

REPORTS FROM OHIO ON MINE SEALING

The Ohio State Health Department gives an encouraging report of progress in the bituminous coal fields in southeastern Ohio, where it has been directing work in fifteen counties and reports 3,548 closures made on abandoned mines up to March 1, 1935 at a cost of $111,802.00. This Department reports in the April issue of the Ohio Health News with respect to stream pollution control as follows:

> It is gratifying to note the improvement in the character of the drainage from some mines which have been completely sealed for periods of six to nine months. The total acidity of such drainage (using phenolphthalein in the cold as indicator) has decreased from 35 to 60 percent, while total phenolphthalein iron content has been lessened by 30 percent. Drainage which in some cases was highly acid to methyl orange has now become alkaline to that indicator. Moreover, the improvement in the character of the drainage from individual mine openings is beginning to have an appreciable effect on streams in southern Ohio, which for years have been heavily polluted by acid mine drainage.

CONCLUSIONS

The mine sealing program designed to reduce and minimize acid mine waste pollution of the Ohio River and its tributaries is a technical problem requiring the best coöperative efforts of mining engineers, sanitary engineers and chemists. It involves constant investi-

gation, research and laboratory tests, because it is entirely a new field of activity.

The program in West Virginia, which has resulted in completely closing 215 mines and maintaining air-sealing on them, and checking flow and relative acidity before and after sealing shows that over *three fourths of the acid has been removed from the drainage from these 215 mines in a period of nine months.*

The protection of public health through safeguarding public water supplies has been the primary objective in reducing acid mine wastes pollution on the Ohio River Basin through coöperative state action.

Further research and study on active mining operations is likely to result in a reduction of acid pollution from active operations and the introduction of new and more economical methods into mining practices with reference to ventilation and drainage.

Because mine wastes pollution is an inter-state problem in its major aspects this watershed pollution control can best be carried on as a Federal project under general Federal coördination.

West Virginia, being the headwaters source of many of the tributaries as well as a primary source of the acid pollution occupies a key position. Work done will not be nullified by failure of some other contributing area and in addition fullest possible benefits will be enjoyed within the boundaries of the state.

Economically, it is known that the *annual expense* caused by the effects of the acid water is many times the *total cost* of the preventive program.

EFFECT OF EXCESS LIME HYDRATE UPON CORROSIVE SOFT WATER

By Frank E. Hale

(Director of Laboratories, Department of Water Supply, New York, N. Y.)

Upon completion of experiments previously described in The Journal[1] it was decided to run tests with various amounts of excess lime hydrate to learn whether corrosion could be decreased or prevented in iron pipe and to ascertain what effect such excess would have upon the other materials. Tanks Nos. 2 and 3 were omitted from these tests as it was feared that the prior sodium silicate treatments might vitiate the results. The other tanks with pipes in place were used, at first without dismantling. While finishing the necessary work of the previous experiments, raw water was run through all pipes until the time of starting the excess lime treatment. The scheme of pipe numbers remained the same and the pipes and treatments used were as follows:

THIRD SERIES	RAW	NEUTRAL 13 P.P.M. CaO_2H_2 0 P.P.M. EXCESS	23 P.P.M. CaO_2H_2 10 P.P.M. EXCESS	63 P.P.M. CaO_2H_2 50 P.P.M. EXCESS	113 P.P.M. CaO_2H_2 100 P.P.M. EXCESS
	Tank 1	Tank 4	Tank 5	Tank 6	Tank 7
Byers, W.I., cold	171	471-A	571	671-A	771-A
Byers, W.I., hot	172	472-A	572	672-A	772-A
Reading, W.I., cold	181	481-A	581	681-A	781-A
Reading, W.I., hot	182	482-A	582	682-A	782-A
Galv. W.I., cold	191	491	591	691	791
Galv. W.I., hot	192	492	592	692	792
Brass, cold	141		541		
Brass, hot	142		542		
Red Brass, cold	151				751
Red Brass, hot	152				752
Copper, cold	1X1		5X1	6X1	7X1
Copper, hot	1X2		5X2	6X2	7X2
Cement-lined steel, cold	1Y1		5Y1		7Y1

[1] Jour. A. W. W. A. Vol. 26, October, 1934, pp. 1314–1347.

The hot water tank was automatically maintained at 150°F. plus or minus 5°. The treatments adopted in this third series were

Tank 1. Raw water.
Tank 4. Free and bicarbonic acid neutralized.
Tank 5. 10 p.p.m. excess lime hydrate.
Tank 6. 50 p.p.m. excess lime hydrate.
Tank 7. 100 p.p.m. excess lime hydrate.

AMOUNTS OF CHEMICALS ADDED

As before the amounts of chemical added were based on average analyses of the raw water and definite amounts of lime hydrate as delivered were added to each tank daily with no attempt to match exactly the changes in raw water. Some trouble was experienced in obtaining uniform admixtures in the tanks, sludge settling to the bottom so that last water deliveries were somewhat stronger than in the beginning of each day's run, but it is believed that the average condition is sufficiently represented in the analyses. Fifteen minutes churning by the electric stirrer was adopted, although 45 minutes gave somewhat more uniform results. In the tables the amount of caustic alkalinity present is expressed as if it were $CaCO_3$. Based on 65 percent CaO average content of the lime hydrate as delivered the latter would be 12.5 percent less than the amount as expressed, if 90 percent CaO_2H_2, 18 percent less lime hydrate as delivered, and calculated to actual 100 percent CaO_2H_2, 26 percent less.

EXCESS LIME TREATMENT CLOGS IRON PIPE

It was soon learned that the 2.5 gallon per hour flow could not be maintained in all of the black wrought-iron pipes. Generally speaking the high lime treatment pipes rapidly clogged, both cold and hot. The cold iron pipes continued for 148 days with reducing flow. One hot pipe stopped completely in 15 days, four others in 124 days, and only five hot pipes lasted 148 days. In the cold pipes, strange to say, increasing amounts of iron came through the taps with increasing amounts of excess lime. In other words the pipes seemed to be unloading rust in colloidal form. These results have been mentioned as showing what might result in applying excess lime treatment to an old iron pipe system previously badly corroded and from which the galvanizing was largely gone. The results have not been included in the tables of this paper as the different results are not comparable. Some of the results are shown on figures 9 to 11. However, reduced

oxygen consumed with increasing excess lime hydrate indicated that further experiments starting with clean pipe would be fruitful. Through the kindness of Mr. Hall and Mr. Speller, of the National Tube Company, the formula used in their experiments for cleaning steel pipe in buildings was obtained, and through kindness of Mr. Cislo, of the Barrett Company, sufficient pickling compound No. 20 was furnished to experiment with the pipes.[2]

The formula calls for 16 percent hydrochloric acid (expressed as pure acid) and 3 percent Barrett's No. 20 inhibitor. Commercial acid, diluted half and half with water, was used. The black wrought-iron pipes were dismantled in convenient lengths, treated with a cutting tool, brushed, treated with the acid and inhibitor, washed clean, and reassembled. Weighed nipples were similarly treated and losses corrected as determined by action on blanks.

THIRD SERIES REPEATED

The third series was then started again with the black wrought-iron pipes and continued for approximately six months. Meantime the treatments had continued on the galvanized wrought-iron pipes, brass, red brass, copper, and cement-lined steel. These lines were not cleaned since flow had been little affected by previous tests and action of any cleaning acid on these metals was uncertain.

Flow in all pipes was maintained at approximately 54 gallons per day, 2¼ gallons per hour (range, 2.1–2.4), if necessary by choosing discs with larger holes to regulate the flow as clogging progressed.

FOURTH SERIES PLANNED

The results indicated such a rapid decrease in oxygen consumed with large amounts of excess lime hydrate that a fourth series was planned with intermediate values between 10 and 50 p.p.m. excess. The raw water and 10 p.p.m. in excess were continued, but the exactly neutralized was discontinued. The black wrought-iron pipes from tanks 4, 6 and 7 were again cleaned as before, but not the other pipes. The same scheme of pipes was in use and the tank treatments were as follows:

[2] Solution of scale in pickling steel, Chappell & Ely, Jour. Ind. Eng. Chem., vol. 22, Nov. 1930, page 1197 and page 1200; The pickling of pipe using commercial inhibitors, same Journal page 1201; also Chappell, same Journal volume 20, 1928, page 582; Cleaning rust from water pipes, E. L. Chappell, Domestic Engineering, Nov. 2, 1929, page 63.

Tank 1. Raw water continued.
Tank 4. 20 p.p.m. excess lime hydrate.
Tank 5. 10 p.p.m. excess lime hydrate continued.
Tank 6. 30 p.p.m. excess lime hydrate.
Tank 7. 40 p.p.m. excess lime hydrate.

This series was maintained for approximately seven months, when the entire experiments were ended. As previously, nipples where available were removed at intervals of six months or more, cleaned, and loss of weight determined. With the black wrought-iron nipples the hydrochloric acid with inhibitor was used, but not with other materials. The lime carbonate deposit where present was hard and difficult to entirely remove.

Flow tests with faucets wide open and with regulating discs removed were also made at intervals as previously. The same chemical analyses were made as previously with samples taken in the same manner.

The results of analyses of the tank waters, averaged for periods corresponding to the different sets of treatment, are given in table 1.

It will be noted that the treatments were sufficiently close to that intended taking into account the method of expression of caustic alkalinity as if it were $CaCO_3$. Neutral or normal alkalinity varied in the treated tank waters with excess caustic from 10 to 27 p.p.m. Solubility of neutral carbonate in water is variously given in the literature, but the most reliable figure is about 13–15 p.p.m. After passage through the pipes neutral alkalinity still remained generally higher than its stated solubility except with the very high caustic excess water. With 100 p.p.m. excess caustic alkalinity, neutral alkalinity was reduced in many instances very low and sometimes to zero. This explains the heavy deposition of calcium carbonate upon the interior of all hot pipes with the higher caustic excesses, as will be brought out later.

General averages for the different treatments, cold and hot, after passing through the pipes are shown in table 2.

Due to differences in length of service, and in some cases in individual pipe line flows, oxygen consumed, weight losses of the iron nipples, and dissolved iron determined in solution have been computed as "milligrams per day per square foot" of interior pipe surface. Values for oxygen consumed were obtained as follows:

$$\frac{\text{P.p.m. oxygen consumed} \times \text{flow in cc. per minute} \times 60 \times 24}{1{,}000 \times \text{area in square feet}}$$

TABLE 1

Analyses of tank waters by periods

TANK SOLUTIONS	LIME HYDRATE		DISSOLVED OXYGEN P.P.M.	DISSOLVED IRON Fe P.P.M.	ALKALINITY (AS $CaCO_3$)			FREE CO_2 P.P.M.	pH	TURBIDITY P.P.M.	COLOR P.P.M.
	Dose p.p.m.	Excess p.p.m.			Total p.p.m.	Caustic p.p.m.	Neutral p.p.m.				
(Oct. 17, 1932—Mar. 14, 1933)											
101	0	0	11.7	.30	8			1.4	7.2	6	16
401	13	0	11.6	.30	22	20	2		9.9	7	18
501	23	10	11.7	.30	33	20	13		10.1	7	19
601	63	50	11.6	.30	78	22	56		10.3	10	18
701	113	100	11.7	.30	142	21	121		10.8	12	21
(Mar. 28, 1933–Nov. 22, 1933)											
101	0	0	9.0	.35	7			2.8	7.0	14	21
401	13	0	9.3	.35	21	18			9.7	16	23
501	23	10	9.4	.35	33	22	10		10.1	17	25
601	63	50	9.5	.35	73	22	51		10.4	21	27
701	113	100	9.4	.35	127	16	111		10.8	17	20
(Oct. 17, 1932–Nov. 27, 1933)											
401	13	0	10.3	.30	22	19			9.8	12	21
601	63	50	10.4	.30	75	22	53		10.3	16	23
701	113	100	10.4	.30	134	18	116		10.8	15	20
(Nov. 28, 1933–June 21, 1934)											
401	33	20	11.8	.50	43	23	20		10.2	22	31
601	43	30	12.0	.45	56	24	32		10.3	26	35
701	53	40	11.9	.50	77	23	54		10.3	27	35
(Mar. 28, 1933–June 21, 1934)											
101	0	0	10.3	.35	8			2.4	7.1	14	22
501	23	10	10.6	.35	33	22	11		10.1	16	25
(Oct. 17, 1932–June 21, 1934)											
101	0	0	10.7	.30	8			2.1	7.1	11	20
501	23	10	10.9	.35	33	21	12		10.1	14	23
(Minimum and Maximum)											
Min.....			6.9	.10						3	9
Max.....			13.2	1.20						75	90

TABLE 2

Average analyses, excess lime hydrate treatment, cold and hot (flow 2.3 gallons per hour)

PIPES	LIME HYDRATE		DATE BEGUN	DATE ENDED	DURATION, DAYS	AVERAGE FLOW, CC./MIN.	OXYGEN CONSUMED (mgm. per day per sq. ft.)	WEIGHT LOSS (mgm. per day per sq. ft.)	IRON DISSOLVED (mgm. per day per sq. ft.)	FLUSHING RATE, SECONDS		TIME, MONTHS	REDUCTION IN FLOW CAPACITY	HCl TEST, EFFERVESCENCE	ALKALINITY, P.P.M.			FREE CO_2, P.P.M.	pH	TURBIDITY	COLOR	NOTES
	P.p.m. dose	P.p.m. excess								Initial	Final				Total	Neutral	Caustic					
Wrought iron, cold, Byers																						
171	0	0			239	147	43.5	224*	12.50	36	56**	6	36%		8			2.3	7.1	1	44	#6
471-A	13	0	3/28/33	11/22/33	239	146	49.8	200*	17.37	33	47**	6	30%	None	22	18	0	0	9.7	6	72	#7
571	23	10			239	148	41.5	275*	15.60	35	45**	6	22%		32	22	10	0	10.1	5	60	#8
471-B	33	20			205	151	48.1	213	23.62	33	38	7	13%	Slight	44	24	20	0	10.2	12	79	#11
671-B	43	30	11/28/33	6/21/34	205	148	30.3	137	3.02	34	38	7	11%	Moderate	55	22	33	0	10.3	−2	5	#12
771-B	53	40			205	152	27.8	112	2.07	30	34	7	12%	Slight	64	22	42	0	10.3	−1	5	#13
671-A	63	50	3/28	11/22/33	239	153	33.2	99*	.00	33	38**	6	15%		72	22	50	0	10.3	−6	−2	#9
771-A	113	100	3/28	11/22/33	239	152	26.0	53*	.00	32	37**	6	14%	Vigorous	120	15	105	0	10.7	−5	−4	#10

History notes of pipe lines

Previous treatments.

Note #1. Lines 171, 172, 181, 182 installed 7/14/30. Treated with raw water for 826 days. Clean nipples installed before new run with raw water begun 10/17/32.

Note #2. Lines 471A, 481A, 472A, 482A installed 7/14/30. Treated with 5 p.p.m. soda ash 730 days, raw water 96 days. Clean nipples for run with 13 p.p.m. lime begun 10/17/32.

Note #3. Lines 571, 572,581, 582 installed 7/14/30. Treated with 10 p.p.m. soda ash 730 days, raw water 96 days. Clean nipples for run with 23 p.p.m. lime begun 10/17/32.

Note #4. Lines 671A, 672A, 681A, 682A installed 7/14/30. Treated with 4.5 p.p.m. lime hydr. 730 days, raw water 96 days. Clean nipples for run with 63 p.p.m. lime begun 10/17/32.

Note #5. Lines 771A, 772A, 781A, 782A installed 7/14/30. Treated with 4 p.p.m. caustic soda 730 days, raw water 96 days. Clean nipples for run with 113 p.p.m. lime begun 10/17/32.

Wrought iron pipes.

Note #6. Lines 171, 172,181, 182. See note 1. Lines cleaned and nipples with acid and inhibitor before new run with raw water begun 3/28/33.

Note #7. Lines 471A, 472A, 481A, 482A. See note 2. Lines cleaned and nipples with acid and inhibitor before new run with 13 p.p.m. lime hydrate begun 3/28/33.

Note #7. Lines 471A, 472A, 481A, 482A. See note 2. Lines cleaned and nipples with acid and inhibitor before new run with raw water begun 3/28/33. Lines 471A, 472A, 481A, 482A. See note 2. Lines cleaned and nipples with acid and inhibitor before new run with 13 p.p.m. lime hydrate begun 3/28/33.

TABLE 2—*Continued*

PIPES	LIME HYDRATE: P.p.m. dose	LIME HYDRATE: P.p.m. excess	DATE BEGUN	DATE ENDED	DURATION, DAYS	AVERAGE FLOW, CC./MIN.	OXYGEN CONSUMED (mgm. per day per sq. ft.)	WEIGHT LOSS (mgm. per day per sq. ft.)	IRON DISSOLVED (mgm. per day per sq. ft.)	FLUSHING RATE, SECONDS: Initial	FLUSHING RATE, SECONDS: Final	TIME, MONTHS	REDUCTION IN FLOW CAPACITY	HCl TEST, EFFERVESCENCE	ALKALINITY, P.P.M.: Total	ALKALINITY, P.P.M.: Neutral	ALKALINITY, P.P.M.: Caustic	FREE CO_2, P.P.M.	pH	TURBIDITY	COLOR	NOTES
Wrought iron, cold, Reading																						
181	0	0	3/28	11/22/33	239	145	43.1	228*	11.34	35	74**	6	53%		8			2.4	7.1	1	44	#6
481-A	13	0	3/28	11/22/33	239	150	50.9	253*	18.87	34	50**	6	32%	None	22	19	0	0	9.7	7	77	#7
581	23	10	3/28	11/22/33	239	152	49.7	210*	27.39	33	42**	6	21%		32	23	9	0	10.1	14	105	#8
481-B	33	20			205	150	44.4	187	23.46	34	40	7	15%	Slight	44	24	20	0	10.2	13	79	#11
681-B	43	30	11/28/33	6/21/34	205	152	27.1	88	3.62	34	38	7	11%	Slight	55	24	31	0	10.3	−2	7	#12
781-B	53	40			205	148	23.1	53	3.02	32	34	7	6%	Slight	64	23	41	0	10.3	−2	3	#13
681-A	63	50	3/28	11/22/33	239	155	25.4	60*	.00	34	37**	6	8%	Vigorous	71	21	50	0	10.3	−6	−2	#9
781-A	113	100	3/28	11/22/33	239	156	20.1	50*	.00	32	38**	6	16%	Vigorous	120	15	105	0	10.7	−6	−5	#10

* These nipples removed after 205 days' service.
** These measurements taken two months before end of period.

Wrought iron, cold, Byers																						
171	0	0	3/28/33	6/21/34	450	147	44.8	204	7.50	36	119	15	70%	None	8			1.8	7.2	1	27	#6
571	23	10			450	146	30.4	201	10.42	35	51	15	31%	Very slight	32	22	10	0	10.1	4	40	#8

Note #8. Lines 571, 572, 581, 582. See note 3. Lines cleaned and nipples with acid and inhibitor before new run with 23 p.p.m. lime hydrate begun 3/28/33.
Note #9. Lines 671A, 672A, 681A, 682A. See note 4. Lines cleaned and nipples with acid and inhibitor before new run with 63 p.p.m. lime hydrate begun 3/28/33.
Note #10. Lines 771A, 772A, 781A, 782A. See note 5. Lines cleaned and nipples with acid and inhibitor before new run with 113 p.p.m. lime hydrate begun 3/28/33.
Note #11. Lines 471B, 472B, 481B, 482B. See note 7. Lines cleaned and nipples with acid and inhibitor before new run with 33 p.p.m. lime hydrate begun 11/28/33.
Note #12. Lines 671B, 672B, 681B, 682B. See note 9. Lines cleaned and nipples with acid and inhibitor before new run with 43 p.p.m. lime hydrate begun 11/28/33.
Note #13. Lines 771B, 772B, 781B, 782B. See note 10. Lines cleaned and nipples with acid and inhibitor before new run with 53 p.p.m. lime hydrate begun 11/28/33.

TABLE 2—*Continued*

PIPE	LIME HYDRATE: P.p.m. dose	LIME HYDRATE: P.p.m. excess	DATE BEGUN	DATE ENDED	DURATION, DAYS	AVERAGE FLOW, CC./MIN.	OXYGEN CONSUMED (mgm. per day per sq. ft.)	WEIGHT LOSS (mgm. per day per sq. ft.)	IRON DISSOLVED (mgm. per day per sq. ft.)	FLUSHING RATE, SECONDS: Initial	FLUSHING RATE, SECONDS: Final	TIME, MONTHS	REDUCTION IN FLOW CAPACITY	HCl TEST, EFFERVESCENCE	ALKALINITY, P.P.M.: Total	ALKALINITY, P.P.M.: Neutral	ALKALINITY, P.P.M.: Caustic	FREE CO_2, P.P.M.	pH	TURBIDITY	COLOR	NOTES
Wrought iron, cold, Reading																						
181	0	0	3/28/33	6/21/34	450	147	43.3	216	7.50	35	112	15	69%	None	8			2.0	7.2	1	27	*6
581	23	10			450	152	35.8	155	17.05	33	50	15	34%	Slight	33	23	10	0	10.1	9	65	*8
Wrought iron, hot, Byers																						
172	0	0	3/28	11/22/33	239	145	63.0	750*	25.58	38	63**	6	40%		8			2.2	7.1	4	119	*6
472-A	13	0	3/28	11/22/33	239	150	58.7	407*	23.94	35	54**	6	34%	None	22	18	0	0	9.7	10	117	*7
572	23	10	3/28	11/22/33	239	154	51.3	294*	9.92	47	56**	6	16%		32	22	10	0	10.1	2	45	*8
472-B	33	20	11/28/33	6/21/34	205	150	43.5	178	7.56	35	42	7	17%	Fairly vigorous	43	24	19	0	10.2	2	19	*11
672-B	43	30			205	148	33.4	161	1.24	38	44	7	14%	Vigorous	53	22	31	0	10.3	−4	0	*12
772-B	53	40			205	151	27.8	60	.00	33	36	7	8%	Vigorous	62	21	41	0	10.3	−4	−1	*13
672-A	63	50	3/28	11/22/33	239	150	32.4	47*	.00	37	46**	6	20%	Very vigorous	67	17	50	0	10.3	−8	−6	*9
772-A	113	100	3/28	11/22/33	239	152	24.9	21*	.00	33	43**	6	23%	Very vigorous	116	13	103	0	10.7	−9	−7	*10
Wrought iron, hot, Reading																						
182	0	0	3/28	11/22/33	239	143	61.5	713*	25.23	38	65**	6	42%		8			2.3	7.1	6	119	*6
482-A	13	0	3/28	11/22/33	239	148	61.1	454*	23.62	36	59**	6	39%	None	22	19	0	0	9.8	10	117	*7
582	23	10	3/28	11/22/33	239	148	52.1	263*	10.36	38	46**	6	17%		32	22	10	0	10.1	2	50	*8
482-B	33	20	11/28/33	6/21/34	205	152	44.0	141	6.81	38	46	7	17%	Fairly vigorous	43	23	20	0	10.2	2	24	*11
682-B	43	30			205	150	32.2	128	.84	38	43	7	12%	Vigorous	54	22	32	0	10.3	−4	0	*12
782-B	53	40			205	147	27.5	65	.00	34	37	7	8%	Vigorous	61	22	39	0	10.3	−3	0	*13
682-A	63	50	3/28	11/22/33	239	148	24.9	45*	.00	37	46**	6	20%	Very vigorous	67	19	48	0	10.3	−8	−5	*9
782-A	113	100	3/28	11/22/33	239	148	20.1	51*	.00	33	43**	6	23%	Very vigorous	115	13	102	0	10.7	−9	−7	*10

* These nipples removed after 205 days' service.

** These measurements taken two months before end of period.

TABLE 2—*Continued*

TABLE 2—*Continued*

PIPES	LIME HYDRATE: P.p.m. dose	LIME HYDRATE: P.p.m. excess	DATE BEGUN	DATE ENDED	DURATION, DAYS	AVERAGE FLOW, CC./MIN.	OXYGEN CONSUMED (mgm. per day per sq. ft.)	WEIGHT LOSS (mgm. per day per sq. ft.)	IRON DISSOLVED (mgm. per day per sq. ft.)	FLUSHING RATE, SECONDS: Initial	FLUSHING RATE, SECONDS: Final	TIME, MONTHS	REDUCTION IN FLOW CAPACITY	HCl TEST, EFFERVESCENCE	ALKALINITY, P.P.M.: Total	ALKALINITY, P.P.M.: Neutral	ALKALINITY, P.P.M.: Caustic	FREE CO_2, P.P.M.	pH	TURBIDITY	COLOR	NOTES
Wrought iron, hot, Byers																						
172	0	0	3/28/33	6/21/34	450	144	64.3	548	24.60	38	156	15	76%	None	9			1.8	7.3	5	98	*6
572	23	10			450	154	36.6	67	5.61	47	66	15	29%	Slight	32	22	10	0	10.1	1	25	*8
Wrought iron, hot, Reading																						
182	0	0	3/28/33	6/21/34	450	144	61.9	547	24.60	38	148	15	74%	None	9			1.9	7.2	6	98	*6
582	23	10			450	149	36.7	101	6.27	38	56	15	32%	Moderate	33	22	11	0	10.1	0	30	*8
Galvanized wrought iron, cold																						
191	0	0	10/17/32	6/21/34	612	152	4.3	48	.00	45	52–76	11–20	13–42%	None	8			1.9	7.2	2	0	*14
491	13	0	10/17/32	11/27/33	407	149	4.7	41*	.00	38	44	11	14%		22	19	0	0	9.8	0	1	*15
591	23	10	10/17/32	6/21/34	612	143	3.3	7	.00	34	36–36	11–20	6–6%	Slight	33	22	11	0	10.1	−2	0	*16
491	33	20	11/28/33	6/21/34	205	150	2.0	38**	.00	45	44	7	0%	Moderate	44	24	20	0	10.2	−5	−5	*19
691	43	30	11/28/33	6/21/34	205	147	1.1	2**	.00	40	40	7	0%	Moderate	57	24	33	0	10.3	−8	−8	*20
791	53	40	11/28/33	6/21/34	205	154	1.3	1**	.00	54	66	7	18%	Fairly vigorous	66	23	43	0	10.3	−9	−8	*21
691	63	50	10/17/32	11/27/33	407	149	1.7	4*	.00	37	39	11	5%		75	23	52	0	10.3	−2	−1	*17
791	113	100	10/17/32	11/27/33	407	162	3.0	+4*	.00	38	47	11	19%		129	14	115	0	10.8	−3	−2	*18

Galvanized wrought iron pipes.

Note *14. Lines 191, 192 installed 7/14/30, treated with raw water for 826 days. Cleaned nipples installed for new run with raw water begun 10/17/32.

Note *15. Lines 491, 492 installed 7/14/30, treated with 5 p.p.m. soda ash for 730 days, and raw water 96 days. Cleaned nipples for run with 13 p.p.m. lime begun 10/17/32.

Note *16. Lines 591, 592 installed 7/14/30, treated with 10 p.p.m. soda ash for 730 days, and raw water 96 days. Cleaned nipples for run with 23 p.p.m. lime begun 10/17/32.

Note *17. Lines 691, 692 installed 7/14/30, treated with 4.5 p.p.m. lime hydrate for 730 days, and raw water 96 days. Cleaned nipples for run with 63 p.p.m. lime begun 10/17/32.

Note *18. Lines 791, 792 installed 7/14/30, treated with 4 p.p.m. caustic soda for 730 days, and raw water 96 days. Cleaned nipples for run with 113 p.p.m. lime begun 10/17/32.

Note *19. Lines 491, 492. See note 15. Also 407 days with 13 p.p.m. lime hydrate. No new nipples installed. New run with 33 p.p.m. lime hydrate begun 11/28/33.

TABLE 2—*Continued*

PIPES	LIME HYDRATE: P.p.m. dose	LIME HYDRATE: P.p.m. excess	DATE BEGUN	DATE ENDED	DURATION, DAYS	AVERAGE FLOW, CC./MIN.	OXYGEN CONSUMED (mgm. per day per sq. ft.)	WEIGHT LOSS (mgm. per day per sq. ft.)	IRON DISSOLVED (mgm. per day per sq. ft.)	FLUSHING RATE, SECONDS: Initial	FLUSHING RATE, SECONDS: Final	TIME, MONTHS	REDUCTION IN FLOW CAPACITY	HCl TEST, EFFERVESCENCE	ALKALINITY, P.P.M.: Total	ALKALINITY, P.P.M.: Neutral	ALKALINITY, P.P.M.: Caustic	FREE CO_2, P.P.M.	pH	TURBIDITY	COLOR	NOTES
Galvanized wrought iron, hot																						
192	0	0	10/17/32	6/21/34	612	149	18.0	149	2.09	50	61–70	11–20	18–29%	None	9			1.6	7.3	1	6	*14
492	13	0	10/17/32	11/27/33	407	151	13.1	107*	.00	45	52	11	13%		22	19	0	0	9.8	2	1	*15
592	23	10	10/17/32	6/21/34	612	156	7.8	25	.00	44	43–45	11–20	0–2%	Very slight	33	22	11	0	10.1	−1	0	*16
492	33	20	11/28/33	6/21/34	205	152	11.4	52**	.00	54	53	7	0%	Fairly vigorous	44	24	20	0	10.2	−6	− 4	*19
692	43	30	11/28/33	6/21/34	205	155	9.3	+86**	.00	79	86	7	8%	Vigorous	55	23	32	0	10.3	−9	−10	*20
792	53	40	11/28/33	6/21/34	205	149	5.7	+69**	.00	166	175	7	5%	Vigorous	64	22	42	0	10.3	−11	− 8	*21
692	63	50	10/17/32	11/27/33	407	157	8.6	+84*	.00	45	67	11	33%		71	20	51	0	10.4	−4	− 2	*17
792	113	100	10/17/32	11/27/33	407	149	5.8	+51*	.00	44	98	11	55%		124	10	114	0	10.8	−7	− 5	*18
Yellow brass, cold (60:40)																						
141	0	0	10/17/32	6/21/34	612	151	2.2			30	31	20	3%		8			2.0	7.1	1	1	*22
541	23	10	10/17/32	6/21/34	612	160	1.0			29	30	20	3%		33	22	11	0	10.1	−1	0	*23
Yellow brass, hot (60:40)																						
142	0	0	10/17/32	6/21/34	612	151	4.1			34	33	20	0%		8			1.9	7.2	1	1	*22
542	23	10	10/17/32	6/21/34	612	152	1.5			31	30	20	0%		33	22	11	0	10.1	−1	0	*23

* Nipples removed after 367 days' service.

** In service 612 days and nipples in service with previous treatment.

Note *20. Lines 691, 692. See note 17. Also 407 days with 63 p.p.m. lime hydrate. No new nipples installed. New run with 43 p.p.m. lime hydrate begun 11/28/33.

Note *21. Lines 791, 792. See note 18. Also 407 days with 113 p.p.m. lime hydrate. No new nipples installed. New run with 53 p.p.m. lime hydrate begun 11/28/33.

Yellow brass.

Note *22. Lines 141, 142 installed 5/15/28. Treated with raw water for 1617 days, (4 years plus). No nipples left, none installed. New raw water run 10/17/32.

Note *23. Lines 541, 542 installed 5/15/28. Treated with 10 p.p.m. soda ash for 1521 days, raw water 96 days. No nipples left, none installed. Run with 33 p.p.m. lime 10/17/32.

TABLE 2—*Continued*

Note #22. Lines 141, 142 installed 5/15/28. Treated with raw water for 1617 days, (4 years plus). No nipples left, none installed. New raw water run 10/17/32.

Note #23. Lines 541, 542 installed 5/15/28. Treated with 10 p.p.m. soda ash for 1521 days, raw water 96 days. No nipples left, none installed. Run with 23 p.p.m. lime 10/17/32.

TABLE 2—*Continued*

PIPES	LIME HYDRATE: P.p.m. dose	LIME HYDRATE: P.p.m. excess	DATE BEGUN	DATE ENDED	DURATION, DAYS	AVERAGE FLOW, CC./MIN.	OXYGEN CONSUMED (mgm. per day per sq. ft.)	WEIGHT LOSS (mgm. per day per sq. ft.)	IRON DISSOLVED (mgm. per day per sq. ft.)	FLUSHING RATE, SECONDS: Initial	FLUSHING RATE, SECONDS: Final	TIME, MONTHS	REDUCTION IN FLOW CAPACITY	HCl TEST, EFFERVESCENCE	ALKALINITY, P.P.M.: Total	ALKALINITY, P.P.M.: Neutral	ALKALINITY, P.P.M.: Caustic	FREE CO_2, P.P.M.	pH	TURBIDITY	COLOR	NOTES
Red brass, cold (85:15)																						
151	0	0	10/17/32	6/21/34	612	153	1.4			31	32	20	3%		8			2.1	7.1	1	1	#24
751	53	40	11/28/33	6/21/34	205	149	0.6			29	29	7	0%		64	22	42	0	10.3	−8	−9	#26
751	113	100	10/17/32	11/27/33	407	154	0.8			29	29	11	0%		129	12	117	0	10.8	−3	−3	#25
Red brass, hot (85:15)																						
152	0	0	10/17/32	6/21/34	612	150	3.8			33	33	20	0%		8			2.1	7.1	1	1	#24
752	53	40	11/28/33	6/21/34	205	146	4.2			87	94	7	7%		62	21	41	0	10.3	−12	−10	#26
752	113	100	10/17/32	11/27/33	407	162	2.6			30	63	11	52%		124	10	114	0	10.8	−7	−5	#25
Copper tubing, cold																						
1X1	0	0	10/17/32	6/21/34	612	142	1.6	5*		32	33	20	3%	None	8			2.1	7.1	1	1	#27
5X1	23	10	10/17/32	6/21/34	612	155	0.6	2*		30	32	20	7%	None	34	23	11	0	10.1	−1	0	#28
6X1	43	30	11/28/33	6/21/34	205	146	0.5	1*		33	34	7	3%	Very slight	57	23	33	0	10.3	−8	−8	#31
7X1	53	40	11/28/33	6/21/34	205	154	0.2	1*		34	33	7	0%	Slight	65	22	43	0	10.3	−9	−8	#32
6X1	63	50	10/17/32	11/27/33	407	149	0.9	2**		32	33	11	3%		76	23	53	0	10.4	−3	0	#29
7X1	113	100	10/17/32	11/27/33	407	156	0.6	2**		32	32	11	0%		128	10	118	0	10.8	−5	−2	#30

Red brass.

Note #24. Lines 151, 152. See note 22, same history and treatment.

Note #25. Lines 751, 752 installed 5/15/28. Treated with 4 p.p.m. caustic soda 1521 days, raw water 96 days. No nipples left, none installed. Run, 113 p.p.m. lime 10/17/32.

Note #26. Lines 751, 752. See note 25. Same history plus 407 days with 113 p.p.m. lime hydrate. New run with 53 p.p.m. lime hydrate begun 11/28/33.

Copper tubing.

Note #27. Line 1X1, 1X2 installed 7/14/30, treated with raw water 826 days. Nipples remained from previous test, used with new run with raw water begun 10/17/32.

Note #28. Lines 5X1, 5X2, installed 7/14/30, treated with 10 p.p.m. soda ash 730 days, raw water 96 days. Nipples remaining used in run with 23 p.p.m. lime hydrate 10/17/32.

Note #29. Lines 6X1, 6X2, installed 7/14/30, treated with 4.5 p.p.m. lime hydrate 730 days, raw water 96 days. Nipples remaining used in run with 63 p.p.m. lime hydrate 10/17/32.

TABLE 2—*Concluded*

PIPES	LIME HYDRATE: P.p.m. dose	LIME HYDRATE: P.p.m. excess	DATE BEGUN	DATE ENDED	DURATION, DAYS	AVERAGE FLOW, CC./MIN.	OXYGEN CONSUMED (mgm. per day per sq. ft.)	WEIGHT LOSS (mgm. per day per sq. ft.)	IRON DISSOLVED (mgm. per day per sq. ft.)	FLUSHING RATE, SECONDS: Initial	FLUSHING RATE, SECONDS: Final	TIME, MONTHS	REDUCTION IN FLOW CAPACITY	HCl TEST, EFFERVESCENCE	ALKALINITY, P.P.M.: Total	ALKALINITY, P.P.M.: Neutral	ALKALINITY, P.P.M.: Caustic	FREE CO_2, P.P.M.	pH	TURBIDITY	COLOR	NOTES
Copper tubing, hot																						
1X2	0	0	10/17/32	6/21/34	612	144	3.3	11*		35	36	20	3%	None	8			2.2	7.1	1	1	#27
5X2	23	10	10/17/32	6/21/34	612	158	1.7	2*		33	34	20	3%	None	33	22	11	0	10.1	−1	0	#28
6X2	43	30	11/28/33	6/21/34	205	153	7.0	4*		59	63	7	6%	Vigorous	56	23	33	0	10.3	−10	−10	#31
7X2	53	40	11/28/33	6/21/34	205	146	4.0	2*		79	106	7	25%	Vigorous	63	22	41	0	10.3	−11	−9	#32
6X2	63	50	10/17/32	11/27/33	407	153	3.4	5**		34	52	11	35%		73	21	51	0	10.4	−4	−2	#29
7X2	113	100	10/17/32	11/27/33	407	162	2.3	4**		32	69	11	54%		125	10	115	0	10.8	−6	−4	#30

* In service 1438 days and nipples in service with previous treatments.
** In service 1193 days and nipples in service with previous treatments.

Cement-lined steel, cold																						
1Y1	0	0	10/17/32	6/21/34	612	150	4.5	59*	.00	52	63	20	17%	None	9			1.3	7.4	1	1	#33
5Y1	23	10	10/17/32	6/21/34	612	157	3.7	32*	.00	48	45	20	0%	Slight	35	23	12	0	10.1	−1	1	#34
7Y1	53	40	11/28/33	6/21/34	205	155	3.2	22*	.00	50	54	7	7%	Fairly vigorous	68	24	44	0	10.3	−6	−7	#36
7Y1	113	100	10/17/32	11/27/33	407	151	4.4	36**	.00	52	49	11	0%		127	11	116	0	10.8	1	2	#35

* In service 1438 days and nipples in service with previous treatments.
** In service 1193 days and nipples in service with previous treatments.

Note #30. Lines 7X1, 7X2 installed 7/14/30, treated with 4 p.p.m. caustic soda 730 days, raw water 96 days. Nipples remaining used in run with 113 p.p.m. lime hydrate 10/17/32.

Note #31. Lines 6X1, 6X2. See note 29. Same history plus 407 days with 63 p.p.m. lime hydrate. New run with 43 p.p.m. lime hydrate begun 11/28/33.

Note #32. Lines 7X1, 7X2. See note 30. Same history plus 407 days with 113 p.p.m. lime hydrate. New run with 53 p.p.m. lime hydrate begun 11/28/33.

Cement-lined steel.

Note #33. Line 1Y1 installed 7/14/30, treated with raw water for 826 days. Nipples remaining from previous test used in new run with raw water begun 10/17/32.

Note #34. Line 5Y1 installed 7/14/30, treated with 10 p.p.m. soda ash for 730 days, raw water 96 days. Nipples remaining used in run, 23 p.p.m. lime hydrate begun 10/17/32.

Note #35. Line 7Y1 installed 7/14/30, treated with 4 p.p.m. caustic soda for 730 days, raw water 96 days. Nipples remaining used in run, 113 p.p.m. lime hydrate begun 10/17/32.

Note #36. Line 7Y1. See note 35. Same history plus 407 days with 113 p.p.m. lime hydrate. New run with 53 p.p.m. lime hydrate begun 11/28/33.

The area of cold lines equals 21.2 square feet.

The area of hot lines equals 25.7 square feet.

That is: P.p.m. oxygen consumed × cc. per min. × .068 = mgm. Ox./Day/sq. ft. & p.p.m. oxygen consumed × cc. per minute × .056 = mgm. Ox./Day/sq. ft. for cold lines and hot lines respectively.

Values for dissolved iron were obtained by taking the p.p.m. iron in the pipe line, subtracting the iron in the corresponding tank solution and using the above method as for oxygen consumed.

Weight loss figures were obtained as follows:

$$\frac{\text{Corrected loss in grams of 6-inch nipple} \times 10 \times 1{,}000}{\text{Number of days in service}}$$

The area of a 6-inch nipple very closely equalled 0.1 sq. ft. The hydrochloric acid test of deposit was made by scraping loose a few particles from the interior of uncleaned nipples into an evaporating dish and adding a few drops of 1:1 hydrochloric acid. The degree of effervescence was noted.

Turbidity and color figures were obtained by subtracting the average turbidity or color in tank solutions from that in individual pipe lines. This procedure was followed because of considerable variation in the raw water during the test period due to effect of storms on the watershed.

Figures for the wrought-iron lines from the tanks 1 and 5 have been averaged for two distinct periods, 239 days for comparison with other lines and 450 days for the full service.

The results shown in table 2 are strikingly consistent in showing reduction of corrosion as excess lime hydrate increases. The different methods of measuring this reduction all in general agree. This is shown by decrease in oxygen consumed, in weight loss of the 6-inch nipples, in iron found in solution, and in less tuberculation as indicated by reduction in flow capacity. Even with the high excess lime treatments the deposit of calcium carbonate had less effect on flow reduction than the tuberculation of previous experiments, due undoubtedly to a more uniform surface and less eddying effect. There was very little lime carbonate deposit in the cold pipes, but very heavy on the hot pipes with the higher excess lime treatments.

The reduction in corrosion was true of all materials, black wrought-iron, galvanized wrought-iron, brass, red brass, copper, and cement-lined steel.

The effect of 10 p.p.m. excess lime hydrate was slower in develop-

Note #30. Line 7Y1. See note 35. Same history plus 407 days with 113 p.p.m. lime hydrate. New run with 53 p.p.m. lime hydrate begun 11/28/32. hydrate begun 10/17/32.

ing, but was appreciable by the end of a year. Note results in table 3.

Beginning with 30 p.p.m. excess lime it is noticeable that the turbidity present at times in the raw water was precipitated and removed either by sedimentation in the tanks or occluded in the deposit on the pipes.

In the cold black wrought-iron pipes there was an increase in colloidal iron coming through to the taps over the raw water until excess lime reached 30 p.p.m. This did not take place in the hot pipes.

It is obvious from the analyses that the amount of iron coming through to the taps was only a small percentage of that which remained in the pipes as deposit or tuberculation. For example, with raw water the average expressed as milligrams per day per square foot for wrought-iron pipe cold was only 12 against 226 weight loss and hot 25 against 732 weight loss.

Figure 1 shows the condition of 6-inch nipples, looking through them, under the various treatments, cold and hot. Nipples were not available for all tests. The decrease in tuberculation is obvious with increase in excess lime hydrate treatment. Also noticeable is the calcium carbonate deposit in hot pipes particularly when excess lime was 50 p.p.m. and 100 p.p.m. However, the time and treatment of these nipples are not strictly comparable and the following history must be taken into account.

History of the photographed nipples

Wrought-iron, black

171, 172, 181, 182.	Raw water, 450 days service.
471A, 472A, 481A, 482A.	Neutralized. 0 excess lime hydrate, 205 days.
571, 572, 581, 582.	10 p.p.m. excess lime hydrate, 450 days.
471B, 472B, 481B, 482B.	20 p.p.m. excess lime hydrate, 205 days.
671B, 672B, 681B, 682B.	30 p.p.m. excess lime hydrate, 205 days.
771B, 772B, 781B, 782B.	40 p.p.m. excess lime hydrate, 205 days.
672A, 681A, 682A.	50 p.p.m. excess lime hydrate, 205 days.
771A, 772A, 781A, 782A.	100 p.p.m. excess lime hydrate, 205 days.

Galvanized wrought iron

191, 192. Raw water, 612 days service.

591, 592. 10 p.p.m. excess lime hydrate, 612 days.

491, 492. 0 excess lime, neutral, 407 days, 20 p.p.m. excess lime hydrate, 205 days.

691, 692. 50 p.p.m. excess lime, 407 days, 30 p.p.m. excess lime hydrate, 205 days.

791, 792. 100 p.p.m. excess lime, 407 days, 40 p.p.m. excess lime hydrate, 205 days.

TABLE 3

Decrease in corrosion by 10 p.p.m. excess lime treatment

(Expressed as percent reduction of each heading)

	COLD REACTION					HOT REACTION			
	Duration of test, days	Oxygen consumed	Weight loss	Dissolved iron	Flow reduction	Oxygen consumed	Weight loss	Dissolved iron	Flow reduction
Wrought iron	450	25	15	Incr.	53	42	85	76	59
Galvanized iron	612	23	85		86	57	83	100	93
Brass (60:40)	612	55			0	63			0
Copper	612	63	60		0	48	82		0
Cement-lined steel	612	18	46		100				

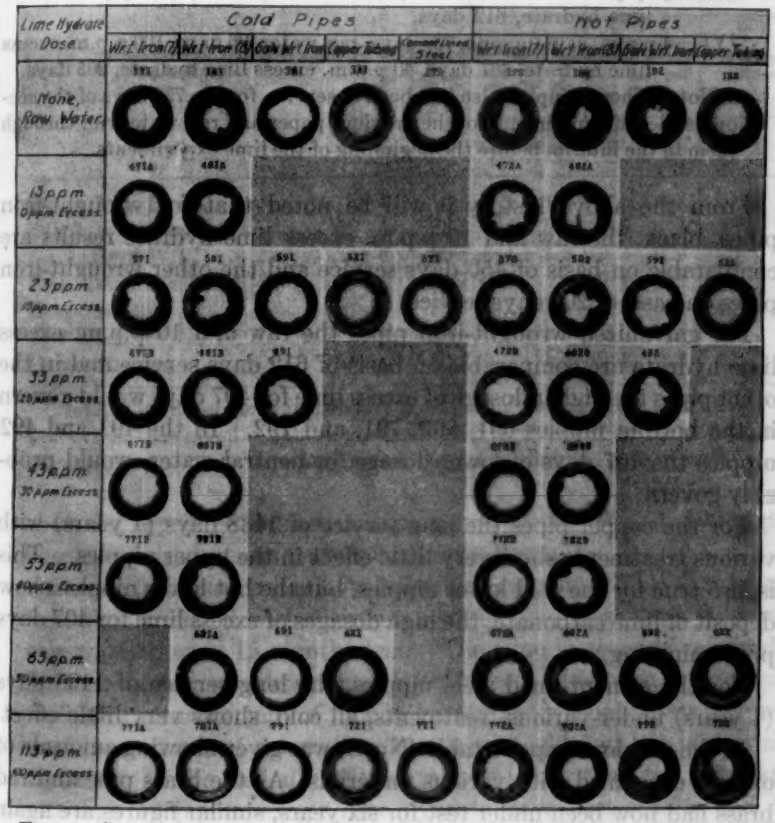


FIG. 1. CROSS-SECTION OF PIPES OF DIFFERENT MATERIALS, SHOWING RESULTS OF THIRD AND FOURTH SERIES OF EXPERIMENTS

Copper tubing

1X1, 1X2. Raw water, 1438 days service.

5X1, 5X2. 10 p.p.m. soda ash, 730 days, raw water, 96 days, 10 p.p.m. excess lime hydrate, 612 days.

6X1, 6X2. 4.5 p.p.m. lime hydrate, 730 days, raw water, 96 days, 50 p.p.m. excess lime hydrate, 407 days, 30 p.p.m. excess lime hydrate, 205 days.

7X1, 7X2. 4 p.p.m. caustic soda, 730 days, raw water, 96 days, 100 p.p.m. excess lime hydrate, 407 days, 40 p.p.m. excess lime hydrate, 205 days.

Note: The above nipples had been in service for the 730 days of the second series of experiments of the previous paper and raw water run through them in the interim before the beginning of the lime experiments.

Cement-lined steel

1Y1. Raw water, 1438 days service.

5Y1. 10 p.p.m. soda ash, 730 days, raw water, 96 days, 10 p.p.m. excess lime hydrate, 612 days.

7Y1. 4 p.p.m. caustic soda, 730 days, raw water, 96 days, 100 p.p.m. excess lime hydrate, 407 days, 40 p.p.m. excess lime hydrate, 205 days.

Note: These nipples also had been in service for the 730 days of the second series of experiments of the previous paper and raw water run through them in the interim before the beginning of the lime experiments.

From the above history it will be noted that for wrought-iron pipes, black, the raw and 10 p.p.m. excess lime hydrate results are comparable on basis of 450 days service and the other wrought-iron pipes on basis of 205 days service.

For galvanized wrought-iron pipes the raw and 10 p.p.m. excess lime hydrate are comparable on basis of 612 days service and in the other pipes the higher dosage of excess lime for 407 days would govern in the bottom nipples 691, 692, 791, and 792. In the 491 and 492 nipples the 407 days of lower dosage, or neutral water, would probably govern.

For the copper pipes the long service of 1438 days (4 years) with various treatments show very little effect in the upper nipples. This is also true for the cold lower nipples, but the hot lower nipples show deposit of lime carbonate, the high dosages of excess lime for 407 days predominating.

For the cement-lined steel nipples, the long service of 1438 days (4 years) under various treatments, all cold, shows very little effect.

In the previous paper a table (No. 6) was given showing amounts of oxygen consumed with various materials. As the brass pipe and red brass had now been under test for six years, similar figures are again

given in table 4, with raw water and also are included results with 10 p.p.m. excess lime hydrate.

The results are astonishingly similar with the raw water after these longer periods of time.

Instead of including the numerous more detailed tables, several diagrams are presented to illustrate various results. Figure 2 shows the corresponding reduction of oxygen consumed, loss of weight of the iron nipples, and decreasing flow reduction with increasing excess lime hydrate in black wrought-iron pipe, both cold and hot, except

TABLE 4

Relation of oxygen consumed, p.p.m., to various materials with raw water and 10 p.p.m. excess lime hydrate

MATERIALS	PIPES IN USE, YEARS	LENGTH OF TEST, MONTHS	RAW WATER		10 P.P.M. EXCESS LIME HYDRATE			
			Oxygen consumed, p.p.m. (2.3 gal. per hr. flow)		Oxygen consumed p.p.m. (2.3 gal. per hr.)		Percent reduced	
			Cold	Hot	Cold	Hot	Cold	Hot
Black W.I. Byers	4	15	4.5	8.0	3.1	4.3	31	46
Black W.I. Reading	4	15	4.4	7.7	3.5	4.4	20	43
Galvanized W.I.	4	20	0.4	2.2	0.3	0.9	25	59
Cem.-lined Steel	4	20	0.5		0.4		20	
Brass (60:40)	6	20	0.2	0.5	0.1	0.2	50	60
Red brass (85:15)	6	20	0.2	0.5				
Copper tubing	4	20	0.2	0.4	0.1	0.2	50	50

Note: The differences in percent removal in the last two columns of this table from that given in table 3 are due to the fact that in the former table the oxygen consumed was expressed as milligrams per day per square foot.

that the deposited calcium carbonate with the 50 and 100 p.p.m. excess lime hydrate had adverse effect in flow.

Figure 3 demonstrates how much less clogging of black wrought-iron pipe occurred with 10 p.p.m. excess lime treatment than with raw water during 15 months test. The time in seconds required to fill a water pail was determined with faucets wide open.

Similar measurement of flow in galvanized wrought-iron pipe with various amounts of excess lime treatment, cold and hot is shown in figure 4. In the cold all treatments were better than the raw water, although 10 p.p.m. excess lime hydrate gave best results and 100

p.p.m. excess lime hydrate the worst results of the treatment. In the hot pipes, again 10 p.p.m. excess gave best results and 50 and 100 p.p.m. excess the worst, much worse than the raw water. The 30

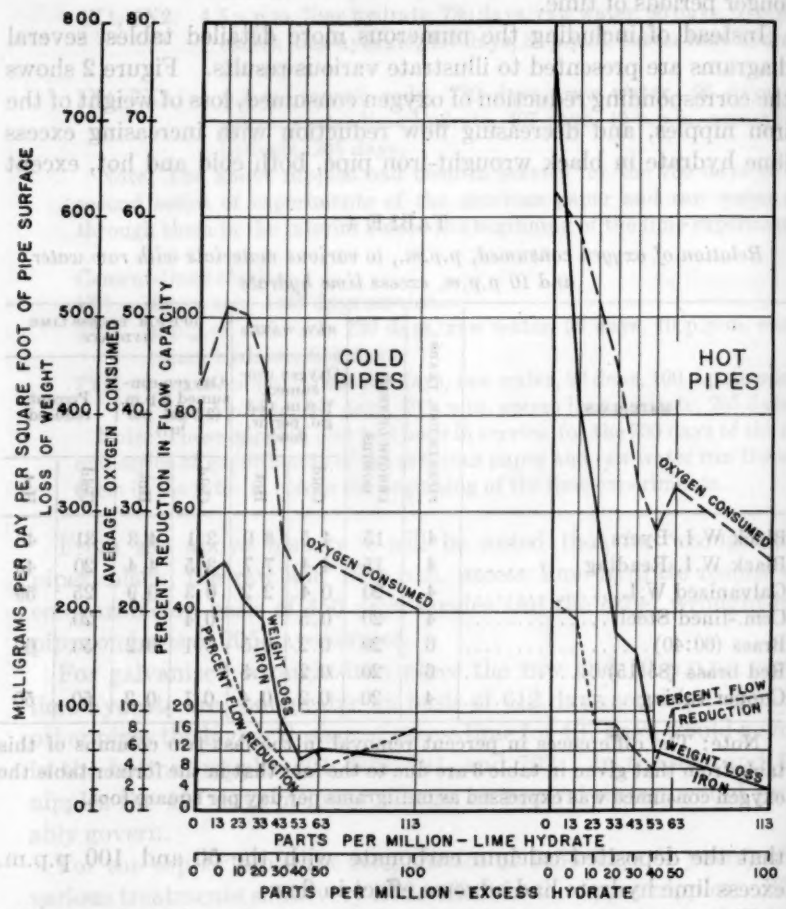

MILLIGRAMS PER DAY PER SQUARE FOOT OF PIPE SURFACE
LOSS OF WEIGHT
AVERAGE OXYGEN CONSUMED
PERCENT REDUCTION IN FLOW CAPACITY
COLD PIPES
HOT PIPES
OXYGEN CONSUMED
WEIGHT LOSS IRON
PERCENT FLOW REDUCTION
0 13 23 33 43 53 63 113
PARTS PER MILLION – LIME HYDRATE
0 0 10 20 30 40 50 100
PARTS PER MILLION – EXCESS HYDRATE

FIG. 2. COMPARISON OF OXYGEN CONSUMED, REDUCTION OF FLOW CAPACITY, AND LOSS OF WEIGHT, OF WROUGHT IRON PIPE, WITH INCREASING AMOUNT OF EXCESS LIME HYDRATE. DURATION OF TESTS—OXYGEN CONSUMED 205–239 DAYS; LOSS IN WEIGHT OF IRON 205 DAYS; PERCENT REDUCTION IN FLOW CAPACITY 6–7 MONTHS.

and 40 p.p.m. excess treatments did not continue to increase clogging at the same rate after the prior higher excess treatments but were similar to the raw water.

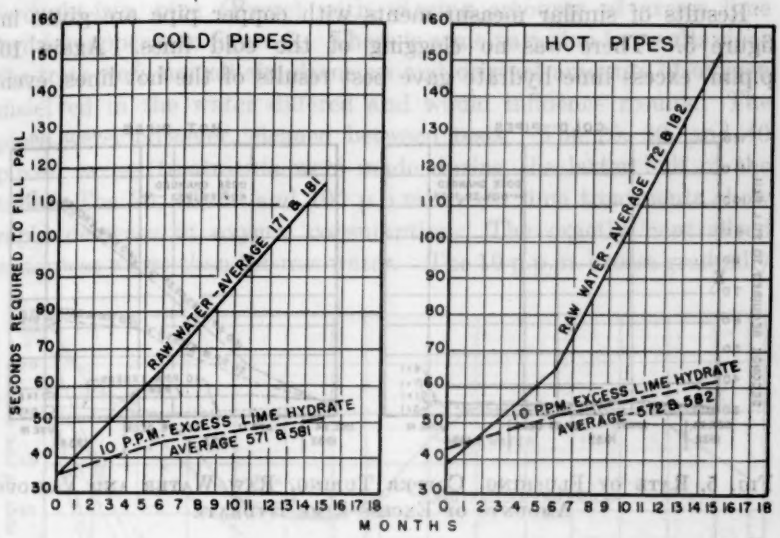

COLD PIPES
HOT PIPES
SECONDS REQUIRED TO FILL PAIL
RAW WATER - AVERAGE 171 & 181
10 P.P.M. EXCESS LIME HYDRATE
AVERAGE 571 & 581
RAW WATER - AVERAGE 172 & 182
10 P.P.M. EXCESS LIME HYDRATE
AVERAGE - 572 & 582
MONTHS

FIG. 3. RATE OF FLUSHING, BLACK WROUGHT IRON PIPE, RAW WATER AND 10 P.P.M. EXCESS LIME HYDRATE

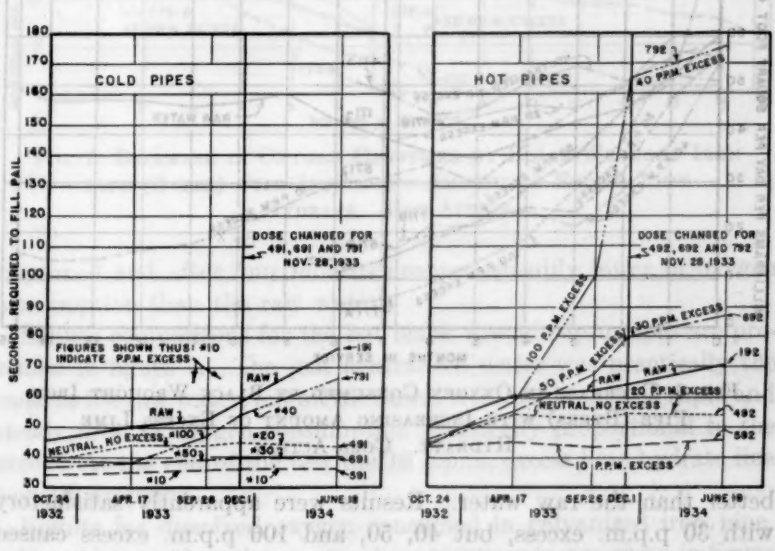


FIG. 4. RATE OF FLUSHING, GALVANIZED WROUGHT IRON PIPE, RAW WATER AND VARIOUS AMOUNTS OF EXCESS LIME HYDRATE

Results of similar measurements with copper pipe are given in figure 5. There was no clogging of the cold lines. Again 10 p.p.m. excess lime hydrate gave best results of the hot lines, even

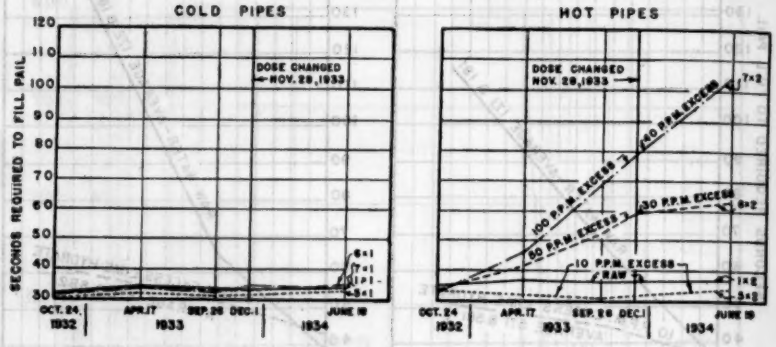


FIG. 5. RATE OF FLUSHING, COPPER TUBING, RAW WATER AND VARIOUS AMOUNTS OF EXCESS LIME HYDRATE

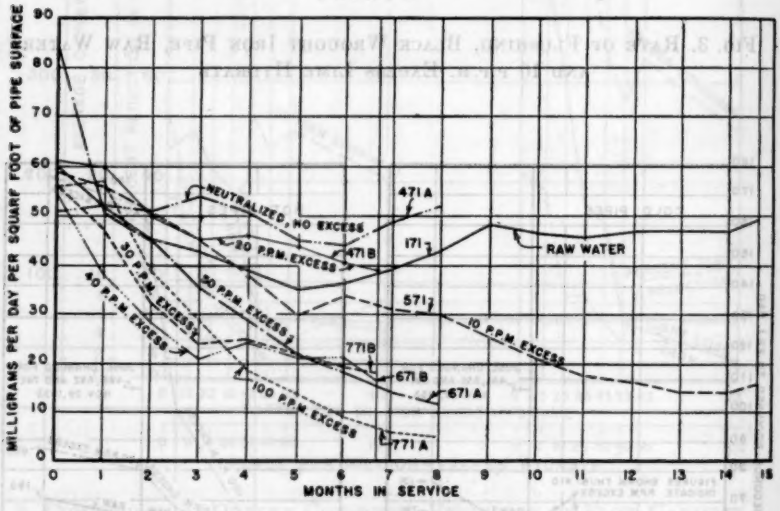


FIG. 6. DECREASE IN OXYGEN CONSUMED BY BLACK WROUGHT IRON PIPE (BYERS) WITH INCREASING AMOUNT OF EXCESS LIME HYDRATE. COLD ACTION

better than the raw water. Results were apparently satisfactory with 30 p.p.m. excess, but 40, 50, and 100 p.p.m. excess caused deposits of calcium carbonate so as rapidly to diminish the flow.

The decrease in oxygen consumption in cold action in black

wrought-iron pipe (Byers) with varying amounts of excess lime hydrate appears in figure 6. There is some variation in results since the tests were not all simultaneous and original amounts of oxygen dissolved in the water differed and would influence results. The pipes were, however, cleaned between tests. The 20, 30, and 40 p.p.m. excess treatments were made during the latter half of the time. The 30, 40, 50 and 100 p.p.m. excess lime treatments show rapid decrease in oxygen consumption. The exactly neutralized water was worse than the raw water. The 10 p.p.m. excess gradually

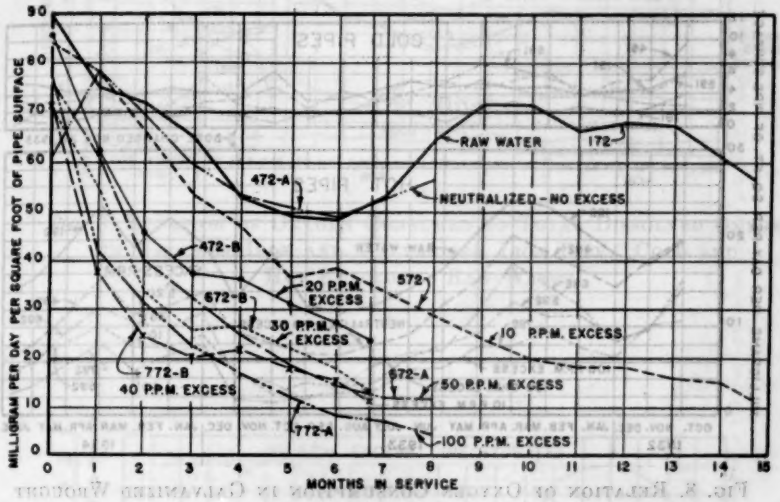


FIG. 7. DECREASE IN OXYGEN CONSUMED BY BLACK WROUGHT IRON PIPE (BYERS) WITH INCREASING AMOUNT OF EXCESS LIME HYDRATE. HOT ACTION

improved and after four months dropped steadily lower in oxygen consumption than the raw water.

Similar comparisons for the hot black wrought-iron pipes are presented in figure 7. The just neutralized water was practically the same as the raw water, but all the excess treatments showed rapid and steady drop in oxygen consumption practically proportional to the excess. At the end of the test the 10 p.p.m. excess lime hydrate line was still dropping.

Results for dissolved oxygen consumed in galvanized iron pipe, cold and hot, with various excess lime treatments, are given in figure 8. The results are not strictly comparable as the galvanized pipes

were not cleaned for the excess lime treatments as they did not show much clogging in the previous experiments. It was also feared that acid treatment would remove the zinc galvanizing. Also as previously stated the 20, 30, and 40 p.p.m. excess treatments took place during the latter half of the experiments and the 30 and 40 p.p.m. excess pipes had previously been used with 50 and 100 p.p.m. excess. However, in the cold pipes results were very much alike and after eight months practically all treatments were better than the raw water. In the hot pipes all treatments, even the exactly neutralized,

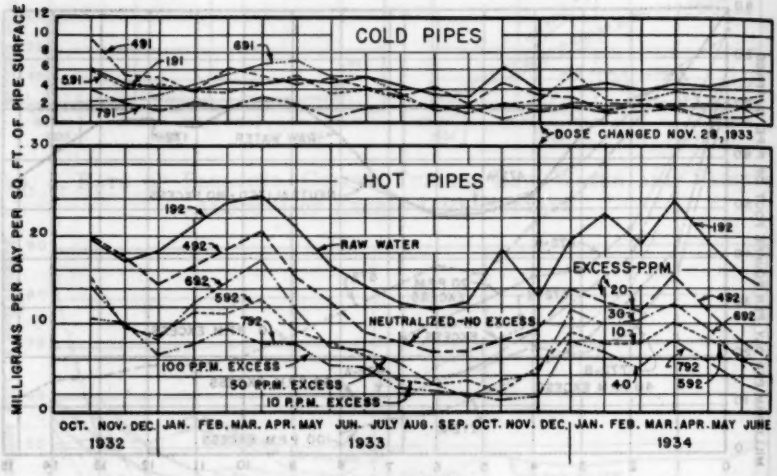


FIG. 8. RELATION OF OXYGEN CONSUMPTION IN GALVANIZED WROUGHT IRON PIPE TO EXCESS LIME HYDRATE IN VARIOUS AMOUNTS. COLD AND HOT REACTION

were well below the raw water in oxygen consumption. The 10 p.p.m. excess lime hydrate was particularly excellent.

Figures 9, 10 and 11 compare dissolved oxygen originally present with oxygen consumed in black wrought-iron and galvanized-iron pipes, cold and hot, when treated with raw water (fig. 9), with 10 p.p.m. excess lime hydrate (fig. 10), and with 30 p.p.m. and 50 p.p.m. excess lime hydrate (fig. 11). The first portion of the charts includes the results on the wrought-iron pipes before they were cleaned. The charts also show the close agreement of results on the two kinds of wrought-iron pipe, Byers and Reading. Figure 9 shows the influence of total original dissolved oxygen on the oxygen consumed, particularly hot action, in both wrought-iron and galvanized-iron pipes, with

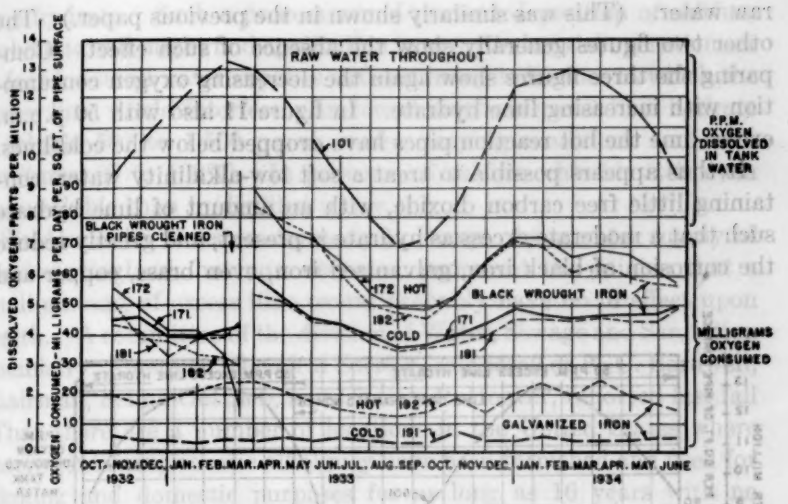


FIG. 9. RELATION OF OXYGEN CONSUMED TO TOTAL DISSOLVED OXYGEN IN WROUGHT IRON AND GALVANIZED IRON PIPE. COLD AND HOT REACTION. RAW WATER

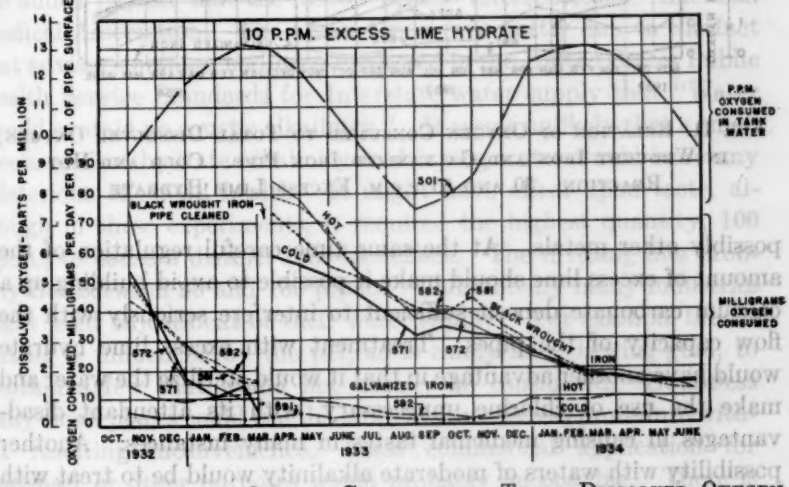


FIG. 10. RELATION OF OXYGEN CONSUMED TO TOTAL DISSOLVED OXYGEN IN WROUGHT IRON AND GALVANIZED IRON PIPE. COLD AND HOT REACTION. 10 P.P.M. EXCESS LIME HYDRATE

raw water. (This was similarly shown in the previous paper.) The other two figures generally show the absence of such effect. Comparing the three figures show again the decreasing oxygen consumption with increasing lime hydrate. In figure 11 also with 50 p.p.m. excess lime the hot reaction pipes have dropped below the cold lines.

It thus appears possible to treat a soft low-alkalinity water, containing little free carbon dioxide, with an amount of lime hydrate such that a moderate excess as hydrate is present, and greatly reduce the corrosion of black iron, galvanized iron, even brass, copper and

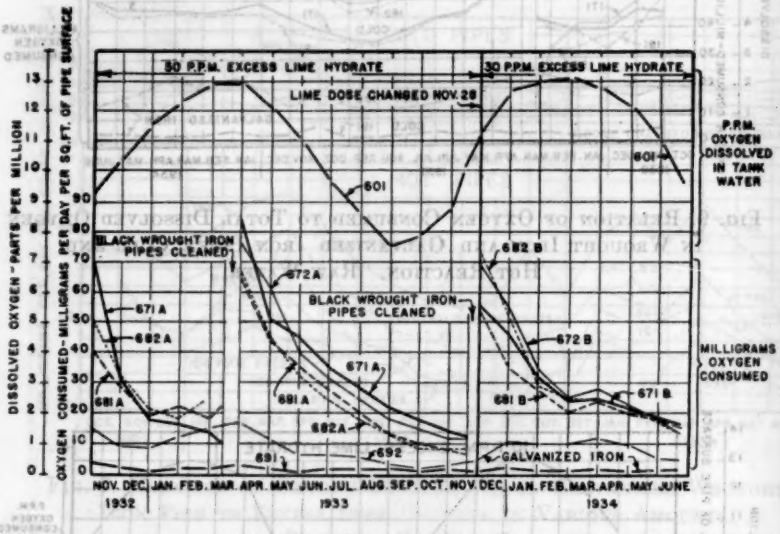


FIG. 11. RELATION OF OXYGEN CONSUMED TO TOTAL DISSOLVED OXYGEN, IN WROUGHT IRON AND GALVANIZED IRON PIPE. COLD AND HOT REACTION. 30 AND 50 P.P.M. EXCESS LIME HYDRATE

possibly other metals. At the same time careful regulation of the amount of excess lime should make it possible to avoid building up a calcium carbonate deposit sufficient to interfere seriously with the flow capacity of the pipes. Treatment with excess lime hydrate would have another advantage in that it would sterilize the water and make the use of chlorine unnecessary, with its attendant disadvantages in causing medicinal tastes in many instances. Another possibility with waters of moderate alkalinity would be to treat with just sufficient hydrochloric acid, to destroy the alkalinity, efficiently aerate to remove carbonic acid set free, and then treat with excess

lime hydrate. Such a process would prevent deposition of calcium carbonate and might find application in many industrial operations or in fact for small water supplies without many industries in which the excess lime would interfere. In round numbers excess lime hydrate is soluble 500 to 1,500 p.p.m. under varying conditions and temperatures, 0° to 100°C. In presence of calcium chloride it is even more soluble than in distilled water.

Sir Alexander Houston, formerly in charge of the water supply of London, England, but now deceased, expressed the opinion that a small amount of excess lime would probably have no ill effect upon health. A committee of the division of Water, Sewage and Sanitation Chemistry, American Chemical Society, composed of R. C. Bardwell, Chairman, Selma Gottlieb, and Charles P. Hoover, reported last fall "That there are a number of locations in the United States where waters containing caustic alkalinity have been furnished and used for drinking and domestic purposes for as long as 16 years with no apparent adverse physiological effects." The report further advised "That the question be referred to the Council with the suggestion that the subject be assigned to the Physiological Chemistry Section of the Division of Biological Chemistry, or the Division of Medicinal Chemistry, for further study, report, and recommendation." The full report was approved by the Division, September 11, 1934, with the added request that the matter be also referred to the American Medical Association. The above report was partly due to the fact that advisory opinion had been expressed in the United States Public Health Service Standards for Interstate water supply that "Water should contain no caustic alkalinity." It seems unlikely that a small excess of lime hydrate alkalinity in drinking water would have any deleterious effect on health. It might have effect upon taste, although in these experiments, it required the highest quantity, 100 p.p.m., to cause a distinct lime-like effect. The dividing line probably lies between 50 and 100 p.p.m. Undoubtedly many industries might need adjustment of their water supply. For example breadmaking is influenced by the pH, so is candy and chewing-gum, to mention a few that would not usually be considered. Doubtless many small places could use the straight Lime excess procedure without resulting inconvenience. Local commercial application for condenser or other purposes would probably be possible. There is some evidence that excess lime hydrate is permissible in low pressure boilers for steam purposes and to prevent corrosion. Under boiler

conditions lime hydrate is soluble to extent of 90 p.p.m., according to Speller.

Quick results with a water like the Catskill could probably be best obtained by feeding enough lime to produce 30 p.p.m. excess for a few weeks and then decrease to 10 p.p.m. excess. Apparently deposition of calcium carbonate depends not only on the amount of neutral (or normal) alkalinity formed within limits, but also on the amount of excess hydrate present, as well as temperature.

To treat New York City's Catskill supply to the extent of 10 p.p.m. excess lime hydrate would require about 1.3 grains per gallon, or 200 pounds per million gallons, that is 60 tons daily for 600 m.g.d. The resulting total alkalinity would be about 35 p.p.m. and total hardness about 50 p.p.m. Whether this would be wise with so many industries involved is another question.

Again I must express my high appreciation for the meticulous care with which the details of these experiments have been carried out, the calculations made and numerous preliminary study-diagrams prepared by Samuel Friedman, Chemist.

CHEMICAL HAZARDS IN WATER WORKS PLANTS

To the Water Works Practice Committee
of the
American Water Works Association.

Greetings:

Your Committee on Chemical Hazards in Water Works Plants begs to report as follows: This committee was not organized until late in October, 1934, and no funds have been available to carry on the work.

Your committee promptly decided that for this first report the study would be limited to chlorine, first, because of the more universal use of chlorine, second, its relatively greater potential danger and, third, the greater amount of data regarding chlorine already available to your committee.

It was also decided that the reactions from this first report would be of great assistance in determining the best procedure in the further study of this and other chemicals. Therefore, the attached report deals only with recommended practice in the handling and utilization of chlorine and the advisable first aid to be rendered those suffering from exposure to chlorine.

We are indebted to Mr. L. L. Hedgpeth of the Pennsylvania Salt Company for special work in the first part of this report and to Mr. H. H. Gerstein, Department of Public Works, Chicago, for the special work in the second part of this report.

Your committee will be glad to continue its work if deemed advisable.

L. H. Enslow,
Geo. H. Fenkell,
H. H. Gerstein,
A. E. Gorman,
R. F. Goudey,
Frank E. Hale,
L. L. Hedgpeth,
Norman J. Howard,
H. S. Hutton,
W. C. Lawrence,
W. S. Mahlie,
M. C. Smith, *Chairman.*

First Report of Committee on Chemical Hazards in Water Works Plants

CHLORINE

Chlorine is a relatively safe commodity to use but its abuse might easily prove fatal. This report is designed to render available information that will aid water works operators in the safe handling of chlorine and the first aid to be given those suffering from exposure to chlorine.

GENERAL CHARACTERISTICS

Chlorine is a chemical element, Symbol Cl, atomic weight 35.46, melting point −151.6° Fahr., boiling point −28.8° Fahr., critical temperature 284.4° Fahr., critical pressure 1374 pounds per square inch. In its gaseous form it has a greenish-yellow color and is about *two-and-one-half* times as *heavy* as air. Liquid chlorine is an amber colored oily liquid about one-and-one-half times as heavy as water.

A cylinder received from the manufacturer may legally contain approximately 88 percent of its volume in the liquid state when at 70° Fahr. The 12 percent remaining volume is occupied by dry chlorine gas. As the gas leaves the cylinders it is not corrosive to metals, but if moisture is present it will rapidly corrode practically all corrosive metals. However, dry chlorine gas becomes very corrosive to metals if heated above 300° Fahr., and it is likely to become corrosive at as low a temperature as 195° Fahr.

Rubber, many synthetic compounds, metallic alloys, as well as the noble metals, are sufficiently resistant to the action of wet chlorine to be satisfactory materials to handle either moist gases or aqueous solutions. However, liquid chlorine cannot be used with rubber, either hard or soft. Chlorine reacts with grease and oils to form a voluminous frothy substance; with gasoline and other petroleum distillates to form a solid complex chlorinated hydro-carbon. Alcohol (ethyl) and ether, even in traces, are converted into solid, waxy, hexachlorethane.

Methane derivatives, chloroform, wood alcohol and carbon tetrachloride are the only safe chlorine equipment cleaners.

ACCIDENTS

Due to the lack of facilities and time, no extended study of the accidents that have occurred in storing and utilization of chlorine in

water works plants has been made by your committee. However, many inquiries have been made of those best informed as to the nature and seriousness of recent accidents. It is interesting to know that but few, if any, deaths are known to have been due to chlorine gas; but many accidents have occurred. It is believed that if the frequency of these accidents is not materially reduced, far more drastic and inconvenient chlorine regulations will certainly result. It is also important to note that a large percentage of these accidents is due either to the leaking fusible plugs at temperatures considerably less than those temperatures which would have created any real danger of container rupture, or to sticking or leaking valves.

Your committee, therefore, praising the recent improvements that have been made recommends that the chlorine manufacturers be requested to further improve the details of construction of the present standard chlorine valve now used on containers. Second, they recommend that the Bureau of Explosives of the Interstate Commerce Commission, having jurisdiction, be urged to consider the advisability of eliminating the fusible plugs now required on all containers, or to so change their nature as to increase the temperature/pressure at which these plugs will operate. This committee will suggest methods by which the above may be accomplished, if these recommendations are approved by the Association.

HANDLING AND STORING

Containers are built of steel and may be safely handled with care. Dropping or bumping containers is extremely dangerous. Facilities used in handling should be carefully arranged to prevent such rough treatment, either through accident or carelessness.

Hoisting is to be avoided as much as is practical; low, rubber tired or jack trucks being preferable. Where hoisting is necessary, safe lifting clamps are preferable to ropes. The use of cables or chains as slings is very dangerous.

Storage should permit the small containers, (up to 150 pounds capacity) to stand vertically, securely prevented from falling over. All containers should be stored in such places as to be shielded from severe mechanical disturbance, such as being hit by other moving materials. Storage should be free from extremes of temperature. Low temperatures are not serious except as noted below under "gassing;" but high temperatures are serious for the additional reason that high pressures exist at high temperature; hence the greater

danger of leaks. No containers should *ever* be stored (or used) near steam radiators nor steam pipes, nor near inflammable materials. In fact, so long as the present fusible plugs are used, when the container reaches a temperature of about 160° Fahr., severe chlorine leaks are certain to result.

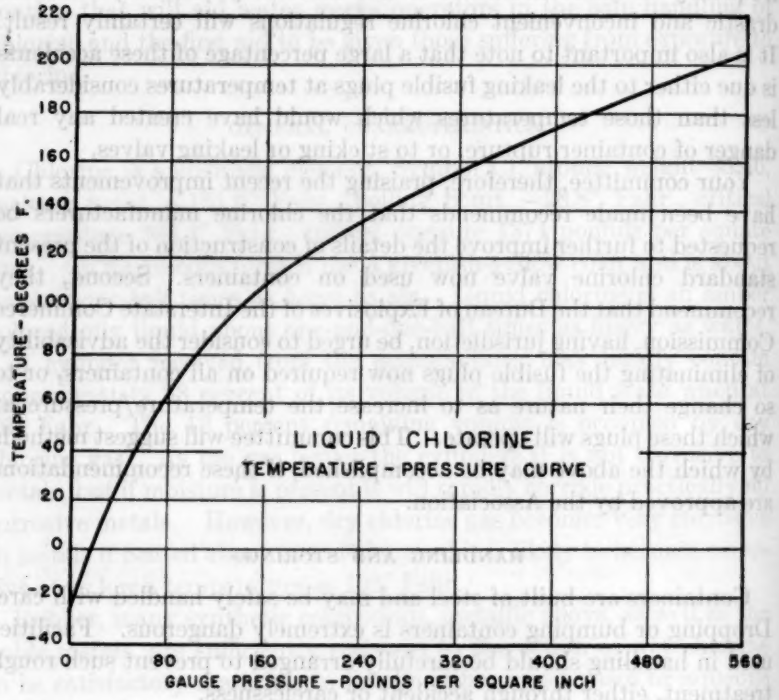


FIG. 1

PHYSICAL CHARACTERISTICS

The temperature/pressure characteristics of chlorine are shown in figure 1 (Knietsch). Chlorine confined in a container may exist as either a gas, liquid, or both. Gas and liquid exist in a state of balance for all conditions of temperature and pressure whose values meet on the curve. If these values meet *above* the curve, the liquid is changing into a gas; if they meet *below* the curve, the gas is condensing into a liquid. This curve, of course, does not apply if a container is entirely filled with liquid.

Figure 2 (Hedgepeth) shows the percent of liquid volume in con-

tainers loaded to the *limit* permitted by the Interstate Commerce Commission regulations. It is seen that with a container filled to this limit at 153.9° Fahr., the cylinder becomes completely filled with liquid and any further increase in temperature will cause greater pressures in the containers. Hence the reason for the fusible plugs which are intended to soften at above this temperature and thus relieve the possibly dangerous pressure. Of course, if any chlorine has been removed from the container, the temperature at which the volume is all occupied by liquid becomes higher and continues to increase as chlorine is removed.

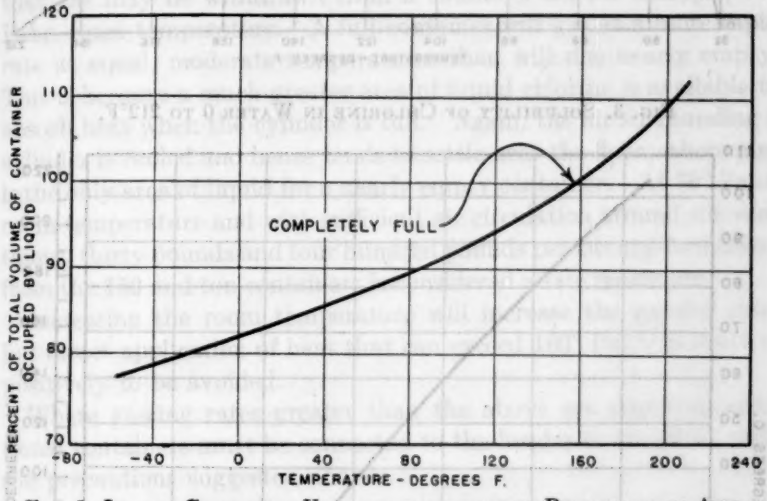


FIG. 2. LIQUID CHLORINE, VOLUME-TEMPERATURE RELATIONS IN ANY LEGALLY LOADED 1-CC. SHIPPING CONTAINER

Conversely, should chlorine be added to a legally full cylinder, this temperature becomes lower. For this reason the valve of a full container should never be opened onto a header until the container is at approximately room temperature. The reason for this caution is that a cold cylinder is apt to have a pressure lower than the header and, therefore, if valve is opened, chlorine would go into the already legally full container.

Figure 3 (Friend) indicates the solubility of chlorine in distilled water, and figure 4 (Mellor) the weight of liquid chlorine at various temperatures.

If gas is drawn from a container, the pressure within the container will be reduced. If a constant supply of gas is to be taken from a

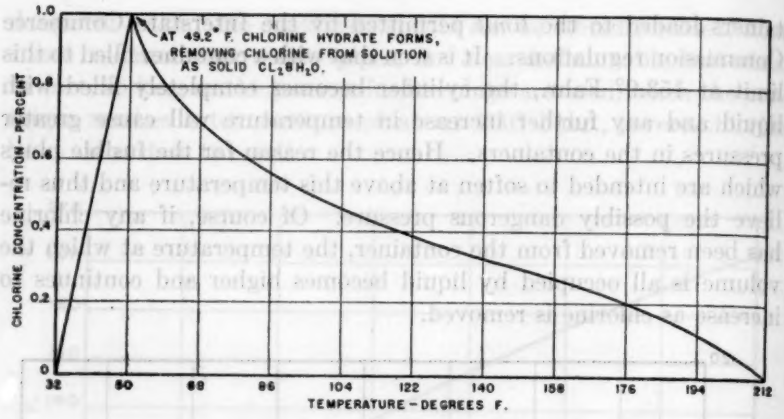


FIG. 3. SOLUBILITY OF CHLORINE IN WATER 0 TO 212°F.

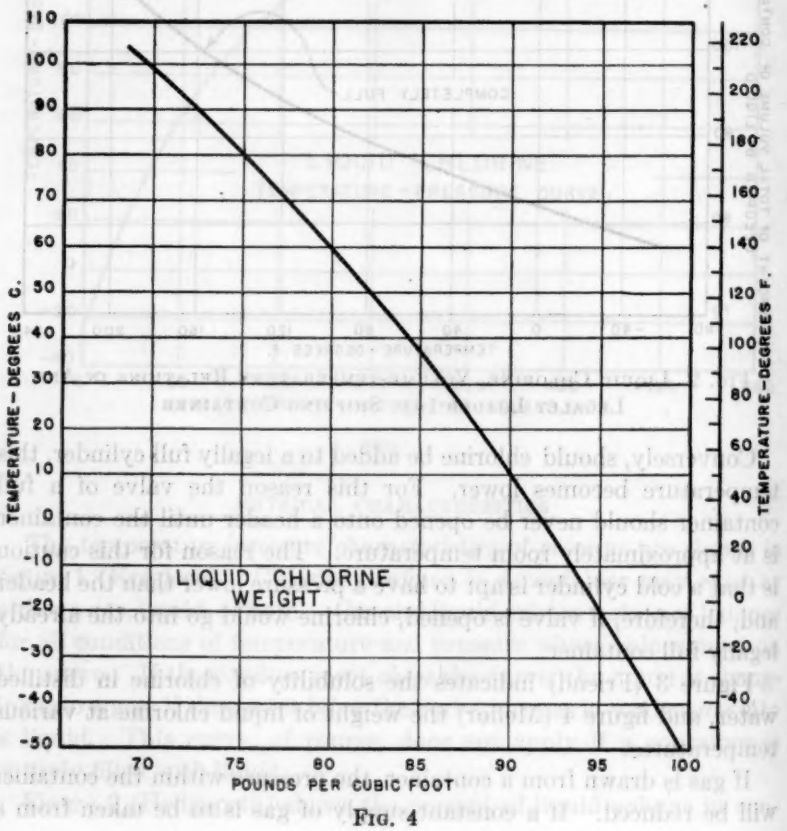


FIG. 4

container, heat must constantly enter the container. The more rapidly gas is removed, the more rapidly heat must enter. This is why the liquid in a gassing container is always cooler than the room temperature. This also explains why it is that in order to maintain pressures in chlorine gas lines the room in which the containers are located must be kept warm. If instead of adding heat, the container is cooled, as by wet blankets, ice packs, or dry ice, the pressure falls rapidly, and the gassing rate is reduced. This is why a cylinder should be cooled as an aid in stopping leaks.

Considerable difference of opinion exists as to the maximum rate that gas may be withdrawn from a container at, for example, 70° Fahr. room temperature. A full container will gas at a more rapid rate at equal, moderate temperatures than will one nearly empty. This is because a much greater area of liquid chlorine is available to absorb heat when the cylinder is full. Again, the air surrounding a cylinder is cooled and hence tends to settle near the floor; where also is the only area of liquid for a nearly empty container. At 70° Fahr. room temperature and with sufficient air circulation around the container, thirty pounds and four hundred pounds per twenty-four hours from the 150 and ton containers is considered a safe maximum.

Increasing the room temperature will increase the gassing rate; but direct application of heat that can exceed 160° Fahr. in itself, is positively to be avoided.

Where gassing rates greater than the above are required, additional containers must be connected to the header or manifold, with the precautions suggested above.

CHLORINE ROOM AND PIPING

Much difference of opinion exists as to the advisability of having containers and control machines (chlorinators) in the same room. Due to the differences in plant layouts, your committee can make no recommendation, except that where the machine is not within full view of the containers, shut-off valves should be installed near the machines to avoid accident.

The connectors between the container and header (or machine) now being used can be much improved, and it is recommended that funds be provided to permit further study of these devices. It is also recommended that these connectors be carefully inspected at frequent intervals and that they be replaced as soon as defects are noticed. It is important that care be taken to avoid bending stresses

being applied at the points of connection; that is, at the ends or unions of the connectors.

The piping between the container and machine should be at least ¾ inch nominal size, not galvanized and designed for 250 pounds per square inch pressure. It should be securely supported in a location safe from mechanical injury, and arranged to drain back, without traps, to the containers. If this is not practical, drip legs should be provided in the low points of the line to collect any condensate. If valves are necessary, they should be designed especially for use with chlorine.

The line should, if possible, be always warmer than the chlorine container room, to avoid condensation and its consequent problems.

Extreme care should be taken to avoid even minute quantities of materials such as grease, alcohols, etc. from entering or being left in the lines. If the lines must be opened they should be immediately capped to avoid entrance of moisture with air. Pipe lines supplying gas directly to the water should be considered as containing wet chlorine.

To repeat, chlorine is a safe commodity to use so long as it is confined. But its potential danger is very real; and every reasonable precaution should be taken to avoid leaks. It is deemed advisable to here call attention to the fact that one cubic foot of liquid chlorine (at about 68° Fahr.) will become about 490 cubic feet of *concentrated* gas. And that one cubic foot of liquid chlorine evaporated in *4,900,000 cubic feet of air* will cause severe coughing and respiratory irritation. Death will almost certainly follow a few minutes' exposure to a concentration of one part of chlorine in one thousand parts of air.

Your committee, therefore, urges constant care in handling chlorine and the maintenance of plant equipment at a high degree of perfection at all times.

It is evident that facilities should be provided to cope with such a hazard should an emergency arise.

Your committee, therefore, recommends that where surrounding property conditions permit, *adequate* and reliable forced ventilation is advisable and relatively inexpensive. Exhaust air ducts for draining air from the room should intake at the floor level and a fan forcing air into the room should drive the chlorine-room atmosphere directly out of the building. In congested districts the exhaust air ducts should discharge into the largest available trunk sewer. Water submergence tanks and water sprays are of questionable value. A

suitably designed steam ejector system, where steam is always available, is perhaps the best means of disposing of escaped chlorine.

GAS MASKS

A suitable number of gas masks (Bureau of Mines) commensurate with the number of employees endangered or required to act in case of a chlorine leak, should be provided and kept in a convenient location not under lock and key and not in the area likely to be heavily affected. Dependence on any masks other than those approved by the U. S. Bureau of Mines for chlorine service is specifically advised against.

Routine inspection of the masks and the operators' ability to use them should be made at least every three months. The person responsible for their maintenance should obtain from the mask maker a statement of the proper maintenance care and be governed accordingly. Special attention should be paid to the condition of the face pieces and spare canisters should be kept on hand.

Available data indicates that approved canisters are good for at least 2 hours' service with a large factor of safety. However, there appears to be considerable difference in the efficiency of the canisters and it is believed that the matter warrants special investigation by an unbiased organization. It is, therefore, recommended that the American Water Works Association request the Bureau of Mines to make the necessary tests to show the relative merits of the two types of canisters for use with chlorine gas.

When more than one hazardous gas is used in the plant, it may be advisable to use a canister that will serve in an emergency that is due to any of these gases.

While no universally applicable instructions can be given in event of a chlorine leak, your committee deems it advisable to offer the following suggestions:

Stop any leak, if possible, as soon as discovered

A leak will eat away the metal around it, thus enlarging the leak and the potential danger, especially is this true if water is applied in an attempt to stop the leak or absorb the gas.

Ventilate the room immediately

The skilled attendant should don his gas mask, with an assistant standing by with his mask ready to assist if needed.

If a liquid leak, roll or manipulate the container until only gas is escaping.

At all costs avoid being excited and refrain from coughing or sneezing.

If the leak cannot be stopped, try to lower the temperature of the container, and empty through the chlorinators as rapidly as possible.

It is well to remember that small leaks may be easily located by an open bottle of aqua ammonia held near the suspected area.

If liquid leak cannot otherwise be controlled, skillful use of water at the leak may cause sufficient chlorine hydrate to form to entirely stop the flow of chlorine, for a time.

Thick loose-fitting gloves and non-porous apron should be worn when attempting to stop any kind of chlorine leak, for skin protection.

Never enter a chlorine atmosphere when breathing heavily; the experienced operator learns to take short, quick, through-the-mouth breath.

GENERAL RECOMMENDATIONS

1. None but reliable and trained men should handle chlorine.
2. Avoid dropping or bumping chlorine containers.
3. Store containers in moderate temperature away from steam lines or fire.
4. Never connect a full container onto a header with other containers until their temperatures are approximately the same.
5. Keep caps on containers, except when in use, and replace when empty.
6. Close valve on container as soon as it is empty.
7. Containers must not be refilled except by permission of the owner and in accordance with Interstate Commerce Commission regulations. Even then it is dangerous and should be done only under technical supervision.
8. Never use container for any purpose other than to contain chlorine. Do not mix gases, allow moisture or air to get into containers; and never use containers as rollers or supports.
9. Never apply flame or blow-torch to container, and any cylinder placed so that it *can* be heated above 160° Fahr. is dangerous.
10. Keep the valves closed at all times on all containers except when actually delivering chlorine.
11. It is illegal to ship a defective or leaking container until entirely emptied. Such container should be plainly marked "Defective."
12. Never be ashamed to call for help in a chlorine emergency.

"FIRST AID" TREATMENTS FOR VICTIMS OF CHLORINE GASSING

Your committee is certain that much improvement can be made in the medical treatment of victims of chlorine gassing. The treatise by Lieut. Col. E. B. Vedder, entitled "The Medical Aspects of Chemical Warfare" published by Williams & Wilkins in 1925 is believed to be the latest and most authoritative work on the subject.

Information regarding treatment of gassed cases has been obtained from the various chlorine manufacturers, Chlorine Feeding Apparatus Manufacturers, The Chlorine Institute, The National Safety Council, The Chemical Officer of the Chicago Area, Chemical Warfare Service, manufacturers of safety equipment and a search of the literature on the subject. At the time this was written no answer to our inquiries had been received from the chief medical officer of the Chemical Warfare Service and the American Medical Association. In Appendix "A" is a bibliography and summarized data regarding the "first aid" treatment recommended by the various authorities. This clearly shows the marked differences in opinion regarding methods of treatment for chlorine gassing.

We wish to impress upon everyone interested that the following "first aid" suggestions are made fully realizing their limitations. We are not attempting to practice medicine, and are no more than suggesting what many believe to be the most effective aid that may be rendered the victim until a trained physician can be obtained.

However, we are of the opinion that there are very few men even in the medical profession who have had sufficient experience or who now have readily available information that would improve their qualifications in severe cases. For this reason we have included here as Appendix "B" an excerpt from Lieut. Col. E. B. Vedder's book, "The Medical Aspects of Chemical Warfare," with the recommendation that every water works' physician and rescue squad be given this information and that the water works' operator maintain the interest of the physician in this matter.

FIRST AID TREATMENT FOR SEVERE CASES

The following "first aid" measures are recommended to be taken *pending the arrival of a physician*; preferably one to whom has previously been given the information contained in Appendix "B."

1. Remove person affected at once to the open air, away from the chlorine fumes. The patient should lie flat with his head slightly lower than his feet. Keep patient quiet and warm and prevent

chilling by wrapping in blankets and use of hot water bottles if necessary. Guard against catching cold, especially if patient perspires freely. *Do not excite or exercise patient.*

2. Call the physician.

3. If patient is unconscious and not breathing, use the prone pressure method of producing artificial respiration, if available call fire department rescue squad, *but be sure that they do not use a pulmotor or other mechanical means of resuscitation* because of the danger of rupturing the lungs of the patient. The patient is usually greatly aided by the application of oxygen with proper equipment.

4. If patient is conscious, give *one* of the following to drink: (a) Hot black coffee; (b) One-half teaspoon of essence of peppermint in one-half glass of hot water.

5. *Do not give patient alcoholic drinks.* This has been found to have harmful effect.

6. Drinking of warm milk or cream will usually relieve throat irritation. Inhaling steam from boiling water to which one teaspoon of tincture of benzoin compound is added is quite helpful in relieving coughing and difficulty in breathing. Inhalation of pure oxygen for short periods under the supervision of a physician usually relieves continued coughing.

TREATMENT FOR VERY MILD CASES

For less severe cases, it should be remembered that only the respiratory tracts are directly affected. Hence, the patient should avoid exposure and fatigue for a time, depending upon the severity of the exposure and the physician's advice.

The following prescription has been used in cases of mild exposure with so much success that it is recommended for the "first aid" kit of water works plants.

Water	1485 cc.
Sugar	45 grams
Tincture of Lavender, Co	37 cc.
Spirits of Ammonia, Aromatic	56 cc.
Alcohol (Ethyl)	333 cc.
Oil of Peppermint	37 cc.
Spirits of Chloroform	55 cc.

Add Oil of Peppermint to the alcohol, then the Spirits of Chloroform, then Spirits of Ammonia and Tincture of Lavender, Co in the

order given. Stir after each addition. Next add this mixture to the water in which the sugar has been dissolved.

Label: For "Chlorine Gas Cough."
"Shake Well Before Using."
Dose—Use as cough syrup—

APPENDIX "A"

SUMMARY OF "FIRST AID" TREATMENT INSTRUCTIONS FOR CHLORINE GASSING—RECOMMENDED BY VARIOUS AUTHORITIES

(Note: Number after each item denotes source of recommendation)

Remove patient to fresh air, away from chlorine fumes. All authorities agree.

Keep patient quiet—absolute quiet and rest. All authorities agree.

Keep patient warm—Wrap in blankets—2, 4, 14.
Hot foot bath—5.
Hot water bottles—14.
Guard against catching cold—5, 7, 13.

Recumbent position—Flat on back—1, 9.
Flat on back—head elevated,—7.
Head low over barrel to drain chlorine from lungs—3.
Lie on side or face with head lower than feet—5.

Resist impulse to cough—1, 7, 9, 13.

Call Physician:
Call physician immediately—1, 4, 7.
Call physician or get patient to hospital, in meantime apply "first aid"—2, 6.

Medicinal treatment:
If conscious, give treatment—1, 9.
Hot coffee—2, 4, 8, 11, 15.
Black coffee—1, 6, 7.
Essence of Peppermint—7, 13.
½ teaspoon Peppermint in hot water—1, 6, 9.
½ teaspoon Peppermint and ½ tsp. Sodium carbonate in ½ glass hot water—5.
½ teaspoon aromatic spirits of ammonia and ½ tsp. Sodium Carbonate in hot water—5.
½ teaspoon aromatic spirits of ammonia in ½ glass of hot water—14.

Bromo-Seltzer—7, 9, 13.

Anti-Chlorine Prescription—2.

Alcohol:

One tablespoon of brandy in hot water—2, 14.

No alcohol—has harmful effect—4, 7.

Smell ammonia fumes—5, 12, 14.

Ammonia fumes harmful—11.

Hypodermic of atrophin—12.

Resuscitation:

If unconscious and not breathing use resuscitation treatment —1, 7, 9.

Use prone pressure method of restoring respiration—1, 6, 7.

Use prone pressure method of restoring respiration, plus oxygen—6.

Use prone pressure method of restoring respiration plus oxygen and CO_2—5, 7, 12.

Do not use prone pressure method of restoring respiration plus oxygen and CO_2—6.

Do not use pulmotor or mechanical pressure method of resuscitation—6, 7.

Give patient inhalations of oxygen—8, 10, 11, 14.

Treatment for relief of irritation of throat, nasal passage and lungs:

Give patient warm milk or cream—4, 5, 7, 8.

Spray throat with 30 percent alcohol—8.

Inhale steam from boiling water to which 1 tsp. tincture benzoin compound is added—2, 4, 16.

Inhale vapors from warm Vicks vapo-rub—2.

Spray throat and nose with oil—4.

Give oxygen treatment to relieve coughing—7, 13.

SOURCES OF INFORMATION "FIRST AID" TREATMENT CHLORINE GASSING

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APPENDIX "B"

Excerpts from "Medical Aspects of Chemical Warfare" by Edward B. Vedder, Lieutenant Colonel, Medical Corps, U. S. A. Published by Williams & Wilkins, 1925.

TREATMENT FOR IRRITANT GAS POISONING, CHLORINE, PHOSGENE, ETC.

Since the war, the observations of all nationalities have become available including the very extensive experimental study of the treatment of phosgene poisoning by Laqueur and Magnun. In addition, experimental work on the treatment of phosgene poisoning has been carried out for several years by the Medical Research Division at Edgewood Arsenal. From the information so obtained, we may say that the treatment of phosgene poisoning should be carried out in accordance with the following logical program.

1. Counteracting the immediate effects of the gas (casual treatment).
2. To reduce or limit the amount of pulmonary edema.
3. To prevent the concentration of the blood.
4. To relieve the anoxemia.
5. To support the heart and circulation.
6. To relieve subjective distress.
7. To prevent infection and subsequent pneumonia.

1. Counteracting the immediate effects of the gas. The damage is done by the intense acid reaction produced by the phosgene in the pulmonary tissue. If this acid could be promptly neutralized, the damage would be greatly lessened. Inhalations of ammonia were used for this purpose by the English and Americans. But Laqueur and Magnun showed clearly on experimental animals not only that this treatment was of no avail, but that it actually increases the mortality, because it was a further source of irritation.

We have found that injections of urease, a ferment that acts on the urea of the blood liberating ammonia, exerts a beneficial action when it is injected intravenously immediately after gassing. Presumably the ammonia so produced is liberated directly into the tissues of the lung, and thus neutralizes promptly a certain portion of the acid. The urease is prepared by making a 10 percent water solution of jack bean meal. An active solution, when mixed with a solution of urea, will turn phenolphthalein pink in less than one minute. One cubic centimeter of this extract is injected intravenously for each 10 kilos of weight, so that 7 cc. should be the dose for a man of average weight. The action of the urease may be hastened by a simultaneous injection of a few grains of urea. Dogs treated in this manner have developed pulmonary edema more slowly and lived longer than untreated control dogs gassed at the same time.

2. To reduce the amount of pulmonary edema. Fluid escapes

into the lungs because of the great dilatation of the pulmonary capillaries and the resultant stasis. If the pulmonary capillaries could be kept constricted, edema would not occur. It seems probable that the injection of urease effects this capillary constriction in addition to neutralizing part of the acid. The mucous membranes of animals so treated become blanched. However, this action in fugacious. A number of drugs have been tested, but the only one that produces this effect over a long period of time is emetine. It has long been known that ipecac reduces pulmonary congestion, and emetine appears to have a constricting effect upon all capillaries, and has been used as a treatment for hemoptysis.

Moreover the action of emetine is prolonged, because its absorption is slow. In treating animals gassed with lethal doses of phosgene, we have found it advantageous to give a single full dose of emetine hydrochloride subcutaneously at the same time that the urease is given intravenously. Animals so treated have developed pulmonary edema much more slowly than untreated animals, or animals treated by urease alone. One-sixth grain emetine is used for each 10 kilos weight or one grain for a man of average weight.

3. Prevention of the concentration of the blood. Injection of gum glucose solution. Attempts have been made to prevent the development of pulmonary edema by increasing the colloids of the blood to such an extent as to prevent the loss of fluid from the capillaries. Laqueur and Magnun found that the intravenous injection of a 25 percent glucose solution saved the life of half of the animals gassed by phosgene that otherwise would have surely died. Barry found in 1923 that edema of the lung clears up to a varying extent when the colloid osmotic pressure of the blood is raised by a 10 percent gum solution.

Experiments conducted at Edgewood Arsenal have shown that dogs may be safely given intravenous injections of a solution composed of 25 percent gum arabic with 25 percent glucose. Five cubic centimeters of this solution is injected slowly for each kilo of body weight. It was found in a series of animals, that if this injection is given soon after gassing (one to two hours), that animals receiving a lethal dose of phosgene may be saved by this treatment alone. This treatment is very much more efficient than venesection, and will actually prevent the development of pulmonary edema unless superlethal concentrations of phosgene are used. Gum glucose solutions may be prepared and sterilized in advance at field hospitals and may

be administered at casualty clearing stations, or possibly even at first aid stations, since the equipment required for such injections is simple in the extreme, consisting simply of a hypodermic needle of a fairly large bore, rubber tubing and a glass irrigator.

The irrigator is filled with hot solution, the needle introduced into a vein, and the injection given slowly. It cannot be given very rapidly since the viscid solution runs through the needle with some difficulty. About twenty minutes should be used for the injection. When given more rapidly it causes some respiratory embarrassment and nausea.

To recapitulate, the treatment of pulmonary irritant gassing in the field should include:

(1) Intravenous injection of urease with or without urea and a subcutaneous injection of one grain emetine hydrochloride at the first aid station. This treatment prolongs the onset of pulmonary edema by several hours, which affords the patient a better chance in any case, and especially may afford the opportunity to transport him to the casualty clearing station or field hospital where other methods may be used.

(2) Injection of gum glucose solution at the earliest possible moment.

4. Measures to relieve the anoxemia. When superlethal concentrations are used, pulmonary edema will develop in spite of the use of gum glucose solution, but only after a greatly prolonged period. Thus a dog that has been treated with gum glucose solution may begin to develop pulmonary edema after twenty to twenty-four hours, while the untreated control may have died in eight to ten hours. For the treatment of the pulmonary edema and resultant anoxemia that occurs, oxygen is required. The result of oxygen therapy is marvellous. An animal that is gasping for breath and is deeply cyanosed, breathes easily and the gums become pink within a few minutes after he is placed in an atmosphere of pure oxygen. The same results were obtained in the treatment of human cases. Even the grey cases resume a normal color. There are only a few cases in which the administration of oxygen fails to completely relieve the cyanosis. With the disappearance of cyanosis the results of anoxemia also vanish. The headache is relieved, the anxiety disappears, the breathing becomes quiet, the sensorium clears and the pulse improves. Patients become quiet and fall asleep with the mask on.

If the oxygen is interrupted, the patient returns to his previous condition more or less rapidly, and in many cases he will himself ask for the mask to be replaced.

Oxygen should therefore be administered continuously and over a long period. The oxygen may be administered by the Haldane apparatus or some similar device which is provided with a mask fitting over the nose and mouth. Improvised methods of giving oxygen are seldom of any value. The best of these methods is administration through a nasal catheter. From 2 to 10 liters of oxygen per minute should be used, or whatever is required to keep the patient's face pink. There will always be need to conserve the supply of oxygen, and therefore it should not be wasted by giving more than is required to keep the patient in good condition. When the face becomes pink and the pulse slows down, he is receiving enough. This treatment must be maintained for hours or even for a day or two, with gradual reduction in the amount of oxygen until recovery is assured and the patient does not become cyanosed when the oxygen is interrupted.

Pure oxygen is irritating to the lungs if it is continued long enough, but at least requires a very long exposure. Men have worn oxygen masks in mine rescue work for at least eight hours without injury. Animal experiments indicate that pure oxygen can be administered safely in a closed chamber for from twenty-four to thirty-six hours, and that 40 to 60 percent oxygen can be breathed almost indefinitely without injury. It will only be necessary to administer pure oxygen during the peak of the edema. Probably no case will require pure oxygen more than twenty-four hours, a period that is entirely safe. As rapidly as possible the percentage of oxygen should be reduced to 60 percent and then 40 percent.

When breathing pure oxygen from a bag and exhaling into the room, there is some possibility that the carbon dioxide tension in the blood may become reduced to such a point that the respiratory center will not be stimulated sufficiently, and respirations will not be efficient. This may be avoided by rebreathing into a bag, or by providing a mixture of oxygen with 1 to 2 percent carbon dioxide. This should cause a very full ventilation of the lungs and assist in reducing the anoxemia. Such precautions are however unnecessary except when oxygen is administered continuously over a very long period. It may also be noted that oxygen cylinders should never be lubricated

with anything except a very pure grade of glycerine. Several disastrous explosions have occurred when oil was used to lubricate valves of oxygen apparatus.

5. Measures to support the heart and circulation. With the development of obstruction to the circulation in the lungs there is a tendency toward dilatation and weakness of the right heart. Camphor and caffeine hypodermically act strongly on the heart and circulation and also on the central nervous system. These drugs are especially applicable before transportation. Alcohol is also a good stimulant, and a small amount of wine or brandy may be used for this purpose. American authorities have condemned the use of digitalis, but German authorities recommend it highly. It is useless given by mouth as it requires seventeen to twenty-two hours for absorption and action. Strophanthin 0.25 mgm., or digipurat, digitalen, or other of the digitalis preparations are recommended intravenously. As with venesection it is claimed that one should not wait until the high point of the disease is reached but that it should be used prophylactically while the heart is still good. When the pulse improves the digitalis should be discontinued. It may be repeated in four hours if required. Caffeine used intravenously is perhaps an even more reliable cardiac stimulant than digitalis, strophanthin or atropine even when these drugs are used intravenously. Two grains caffeine sodiobenzoate may be injected intravenously.

6. Measures to relieve subjective distress. The thirst from which patients suffer may be relieved by free administration of water, or better tea or coffee.

Cough is generally beneficial when it results in the expectoration of fluid. Violent and racking cough following chlorine gassing is often relieved when the patient is put to bed. It may be useful to give inhalations of various soothing mixtures to relieve this condition. Morphine should not be used. In case of necessity a little codeine may be used. The headache is a symptom of anoxemia, and is best treated by oxygen inhalations.

In a later stage, when bronchitis has developed, potassium iodide and ipecac have been highly recommended as expectorants.

Drugs that are counterindicated. There is very little drug treatment other than the above. Most remedies are injurious. The effect of morphine and phenacetin and similar drugs on the circulation is bad. Adrenalin has been tried and found injurious. The same may be said of putuitrin. Amyl nitrite is a heart tonic but it lowers blood pressure, which is already falling rapidly.

7. Measures to prevent infection. After the gassed cases have recovered from the acute pulmonary edema, they will need careful nursing and watching for several weeks. In gas poisoning we are dealing with a serious affection of the lungs, and there is always a possibility of infection and development of bronchopneumonia. There should be a careful mouth hygiene, especially among those seriously ill, the air should be kept dust free as far as possible, and any cases of pneumonia should be promptly removed from the other gassed cases in order to prevent the transfer of infection. If laboratory facilities are available a routine swabbing of the throat of gassed cases and an examination for pneumococci and hemolytic streptococci, would be advisable. Gases harboring these organisms could be treated in separate rooms or wards, and thus the great majority of gassed cases might be protected from pneumonia, resulting from the introduction into the ward of a relatively small number of carriers of these organisms.

Prognosis. The future of an individual case can be told by the condition of the heart and the hemoglobin. A rising hemoglobin and red cell count indicates that the edema is progressing. A falling hemoglobin indicates that the peak of edema has been passed. If the heart stands up through the peak of the edema, the chances of recovery are excellent. The passage of a case from the blue type of asphyxia in which the face is congested and cyanosed to the grey type with an ashen pallor and pale lips indicates failing cardiac action and a correspondingly gloomy prognosis.

It must be remembered that cases that have been gassed with chlorine run their course to a fatal issue much more rapidly than cases gassed by phosgene, and that if treatment is to be successful in chlorine poisoning it must be correspondingly early.

It becomes a matter of acute interest to determine how long such cases should remain in hospital, and when they will be fit for duty again. A study of this question was made in England based upon 4575 gassed cases. In brief it was found that such cases averaged six weeks in hospital. But no such general rule will serve, some cases requiring less and others much more. A prolonged stay in hospital probably shortens eventual convalescence, and a short stay may mean a long subsequent convalescence. The surgeon must base his decision on the severeness of the primary gassing and symptoms immediately following, or the presence or absence of pulmonary complications and the actual condition of the patient at the time.

In this same study the total period of disability, i.e., the period

between the date of gassing to the date of rejoining the Reserve Station, was studied. The duration of this period varied greatly. The majority were returned to duty between the tenth and nineteenth week, but 25 percent of the cases required over twenty-six weeks to return to duty.

Of these cases 67 were readmitted to hospital for symptoms referable to gas poisoning, and it was found that practically the same symptoms that prolong the original stay in hospital are operative in necessitating readmission. Of these 67 cases, 42 eventually returned to duty, while 6 or 9 percent were discharged as permanently unfit. It will thus be seen that of the total 4475 cases only 6 or approximately a tenth of one percent were finally discharged as unfit for further duty.

The question as to when a man is fit for duty is to be settled preferably by a practical test. The men should walk a measured mile briskly with an observer. If he cannot do this, or if this exercise produces dyspnea, or disordered heart action it is sufficiently obvious that he is not yet fit for duty. Should he pass this test, he may repeat this walk with his pack. By making practical tests of this character on cases that appear fit from a medical examination, there should be few cases returned to hospital.

There is a type of case, fortunately rather rare, in which convalescence is disturbed by the occurrence of attacks somewhat resembling spasmodic asthma. These attacks may occur every night, or less frequently. During the attack, the patient is obliged to sit up in bed, and his respiration is shallow and rapid, but not difficult, in which respect it differs from asthma. Slight cyanosis may be present, and the patient is anxious. Often the pulse is rapid during the attack, at other times slow and full. Such cases are suffering from polycythemia. The red corpuscles are increased to six or seven million, and the hemoglobin to 110 or higher, and this condition may persist for several weeks. This condition was studied by Barcroft, Hunt and Dufton. These observers found that the symptoms complained of were: (1) disordered cardiac action; (2) nocturnal dyspnea; (3) high red blood counts; (4) low percentage of CO_2 in alveolar air; (5) acidosis and kindred conditions. The whole train of symptoms is the same as that exhibited at high altitudes.

The treatment consisted in keeping the patients in a chamber containing an atmosphere of 40 to 60 percent oxygen. The CO_2 and aqueous vapor were removed by passing the air over soda lime and

calcium chloride. As a rule the patients remained in the chamber for sixteen out of twenty-four hours for five days. They slept in the chamber every night, left the chamber after breakfast, and returned again just before tea. The tests used were: (1) blood test (of polycythemia), (2) a pulse test, and (3) a respiration test.

These observers reached the following conclusions:

1. A description is given above of 26 cases of gas poisoning. They were treated by the continuous administration of oxygen. The patients were placed in chambers in which the percentage of oxygen aimed at, and usually maintained, was between 40 and 50. The usual term of residence was five days, sixteen or seventeen hours of each day being spent in the chambers. The night was always spent in them.

2. Red cell count. The effect upon the red cell count is as follows: If the red cell count is markedly higher than 5 millions, it is reduced by residence in oxygen, usually to just about that figure; if the red count, as is often the case, especially with mustard gas, is not raised above 5 million residence in oxygen does not alter it. The subsequent history of cases differs: In some the red count tends to rise, in others it remains nearly normal at the end of the two and one-half months. As the red count fell, there was usually a fall—but a much slighter one—in the hemoglobin; the color index therefore rose.

3. Pulse. An almost constant sign in the gassed cases which we have studied has been a failure on the part of the pulse to return normally after exercise to the resting rate. This condition has been benefited by the oxygen treatment in nearly all cases; and in about half it was brought to—or almost to—the normal condition.

4. Nocturnal dyspnea. Of fourteen cases treated in series 1, six suffered from nocturnal attacks of dyspnea. None of these had attacks in the chamber; three appeared to be permanently cured, and two others permanently benefited.

5. Breathlessness on exercise. No measurements were made in the first series of cases; the patients, however, all stated that they were able to walk faster and with less distress than before the treatment. In the second series of cases a definite test for dyspnea was introduced, in which the opinion of the patients was not involved. Of the 6 cases thoroughly tested, 4 increased the quantity of work which they could do with a given degree of breathlessness by over 20 percent, and 2 others by over 10 percent.

A still smaller number of cases suffer from long continued dyspnea

on exertion. Haldane believed that this is partly due to the fact that the alveolar epithelium has not entirely recovered, because the administration of oxygen enables them to perform muscular work more easily. But this is not the whole explanation because even with oxygen, the pulse remains abnormal and breathing is increased in frequency but not in depth as it should be. Haldane's explanation which appears to be reasonable, is that inspiration and expiration are governed by a reflex described by Hering and Breuer. This reflex fires off depending on the degree to which the center is stimulated by CO_2, and breathing naturally became deeper during muscular work. The dyspnea in chronic gas cases, like the "soldiers heart," is caused by neurasthenia. The central nervous system which ordinarily controls the Hering and Breuer reflex is exhausted, and the reflex becomes excessive. The patients cannot restrain it. This is shown by the fact that such patients can not hold their breath for more than a few seconds. It may also be shown by breathing against a resistance. When the resistance is excessive, breathing becomes shallower and more frequent and anoxemia results, and face becomes blue. This change is due to exhaustion of the respiratory center. When this occurs, the reflex gets the upper hand and controls the breathing. In some persons this effect is produced more readily than in others.

In some cases of gas poisoning the respiratory center becomes exhausted and neurasthenic, and reflexes run riot through weakening of central control. Exhaustion in general is the cause of all neurasthenia. "Soldiers heart" is caused from over exertion. The treatment of such a condition, which is a very common basis for claims for pension or war relief, is in reality the treatment of neurasthenia. Gassing is only responsible for this condition in so far as it has led to the development of neurasthenia. In other words, it must be clearly recognized that the more or less permanent dyspnea and disordered heart action suffered by a small proportion of gassed cases, is functional, and is not caused by any organic disability suffered by the lungs themselves.

REPORT OF JOINT EDITORIAL COMMITTEE, STANDARD METHODS FOR THE EXAMINATION OF WATER AND SEWAGE

This report covers activities of the Editorial Committee in preparation of the 8th edition of "Standard Methods for the Examination of Water and Sewage," up to July 1, 1935.

On June 18, 19 and 20, 1935, a conference of all the members of the committee, except Dr. Hatfield (who was in Mexico at the time), was held in Indianapolis. Detailed discussions of various features of the revision of text were carried on, and definite assignments for completion of certain sections made to members of the committee.

At this time it is proper to advise you in some detail as to the changes contemplated for the next edition.

The section on Turbidity will be re-arranged and condensed. The section on Color will be re-written. Studies on Odor Determination by Prof. Fair and Mr. Spaulding will be used in the revision of this section. The text on Oxygen Consumed will be condensed. The Residue on Evaporation text will be extended to include a section on "highly mineralized waters." A method for Residual Aluminium will be added. The Chloride text will be revised. The much discussed section on Chlorine will be revised and expanded to the end that this very important test may be performed correctly under various types of interfering situations. The sections on Lead, Zinc, Copper, Tin, will be revised and condensed, if possible. Changes in the Dissolved Oxygen text will be made as active workers in the field agree upon details.

The sections on Mineral Analysis and Boiler Water Analysis (pp. 65–79) have been fully discussed by the Committee. It is agreed that a general heading of "Industrial Water Analysis" will be used to include two divisions of material. The first, "Municipal and Railroad Supplies," is assigned to Dr. Buswell for development. This section will include the text on "Hardness," (XV), Alkalinity and Acidity (XVI) and Hydrogen Ion Concentration (XVII), which will be re-arranged and condensed as much as is possible and proper. The Section on "Stationary Boiler Supplies" will contain material

developed by the Boiler Feed Water research groups working for several years under Mr. Powell's direction.

Dr. Hatfield has completed the sections on Sewage and Sludge. They were published in the May, 1935, Sewage Works Journal. Changes indicated by criticism after this publication will be embodied in the text as printed in Standard Methods.

Mr. T. A. Olson has revised the section on Microscopic Methods. It has been studied by Prof. Fair, who developed the text in the current edition. The material is approaching final form.

The section on Bacteriological Methods is being developed under Dr. Norton's direction. Mr. Ruchhoft, as Chairman of a committee of laboratory workers, has directed a series of studies of the various selective planting media for Coli-Aerogenes group work that have been in use in this country. The results of part of this work were presented at the A. W. W. A. Cincinnati meeting in a paper entitled, "Study of Selective Media for Coli-Aerogenes Isolation." It is published in this issue of the Journal. Contemplated changes in the section on Bacteriological Methods include:

Deletion of the time-honored 10 percent criterion of gas production in the presumptive test for Coli-Aerogenes to the effect that any amount of "gas" production in the closed arm of the fermentation tube be presumptive evidence of the presence of this type of organisms. Modification of the "Confirmed" test to permit the use of a liquid medium of the "selective" type as the second step in confirmation instead of the present plate technic. It must be recognized that this brings into routine use on any type of water the confirmatory value of such liquid media as Stark's formate ricinoleate broth, crystal violet broth, brilliant green bile, etc. This is contemplated upon the evidence that by such change the value of the confirmed test will be greatly enhanced. It is probable that the majority of laboratories will limit their Coli-Aerogenes diagnostic work to "confirmation."

American Standard Practice in Coli-Aerogenes group study has been much more specific and detailed than that current in other countries. This is evidenced by the following quotation from a paper as yet unpublished, written by a research worker in India:

"The standard routine practice in England and the British Empire generally—including India, Burmah, Ceylon, Hongkong, and all other tropical possessions in Africa and in the Far East—has been preliminary enrichment in MacConkey's medium and reading off the results—acid and gas production—

at the end of 24 and 48 hour's incubation at 37°C. Confirmations are usually made only in the case of stray samples from sources under investigation, or from sources whose antecedents are unknown.

In France, and possibly also in all French possessions, preliminary enrichment in phenol broth and subsequent confirmation on phenol agar constitute the established routine procedure (Dienert and Etrillard, 1930).

In Germany, lactose-peptone-azolitmin solution, Eijkman's glucose peptone solution, and Bulir's neutral mannite bouillon are used for the B. coli tests. These media have received the official sanction of the Prussian Public Health Board (Schoetz, 1932).

In Sweden, the direct plate count on Congo-red agar has been the most favorite test and the one officially recognized and in successful use for many years (Russ, 1926).

In Italy, Parietti's method of determining the coli index is considered the most sensitive and economical method. It has been successfully used to obtain results which have conformed with the requirement of the Ministerial Decree (Segre, 1929)."

Such a review of foreign practice at least indicates that simplification of prescribed routine Coli-Aerogenes technic would not be a radical departure from other-national practice.

Calculation of Coli-Aerogenes density will (if present plans continue) be based upon the "Most Probable Number" methods earlier outlined by McCrady and others, and recently re-studied by Hoskins. This will involve many laboratories in more "primary" plantings than they have been accustomed to take, but by the change in the "confirmed" technic will add nothing to the net burden in the laboratory.

This outline of changes at present contemplated in the text of Standard Methods is presented now in order that the Committee on Water Works Practice and the Board of Directors, A. W. W. A., may be advised as to the important modifications in procedure. In the ordinary course of revision, the Joint Editorial Committee will exchange views until substantial agreement upon all details is reached. Thereupon a final typescript will be prepared for the printer and a copy forwarded to the Chairman of the Committee on Water Works Practice for his approval. This may be expected about November 1, 1935.

It will be understood that, while it is within the power of the Committee on Water Works Practice, as well as the Board of Directors, to withhold approval until a detailed study is made by all members of each group, it is hoped that the policy followed in 1932 will be continued, in which approval power was exercised by the Chairman of the Committee on Water Works Practice.

You are now advised as to the principal points of change planned for the 8th Edition and you may be assured that the Joint Editorial Board is not unmindful of the necessity of conservatism in the preparation of a manual of this type, and at the same time is aware of the necessity of keeping it adequately in step with progress in water treatment practice and maintaining its value as a guide to the laboratory worker.

HARRY E. JORDAN,
Chairman.

(Report made to the Committee on Water Works Practice and to the Board of Directors, A. W. W. A.)

ABSTRACTS OF WATER WORKS LITERATURE

FRANK HANNAN

Key: American Journal of Public Health, 12: 1, 16, January, 1922. The figure 12 refers to the volume, 1 to the number of the issue, and 16 to the page of the Journal.

Some Modern Methods of Chemical Analysis and Their Application to Water. J. GRANT. Water and Water Engineering, 36: 437, 470–471, August, 1934. In titration of **chlorides** with silver nitrate, adsorption indicator, e.g., tartrazine, or rhodamine 6 G, may be used, thus obviating errors due to solubility of silver salts. End point with rhodamine can be sharpened by titration in ultra-violet light. **Sulfates** are determined in 200 cc. of water, after acidification with hydrochloric acid, by adding excess of 0.02 *N* barium chloride and titration of excess barium chloride with 0.02 *N* sodium sulfate until no red color is produced with freshly prepared 0.2 percent aqueous sodium rhodizonate as external indicator. For **hardness**, sample is neutralized to methyl orange, carbon dioxide is boiled out, and calcium and magnesium are titrated with soap solution until red color produced with phenolphthalein. For **carbonates**, gas evolved by boiling sample with acid is passed into 0.5 percent phenolphthalein solution which has been made 0.0025 *N* in sodium hydroxide solution and resulting color is compared with standards made from sodium carbonate. **Aluminum** in treated waters is determined by adding to 5 cc. water (evaporated if necessary) 2 cc. 5 *N* hydrochloric acid, 5 cc. *N* ammonium acetate, 20 cc. 50 percent glycerol, and 5 cc. 0.2 percent aqueous aurin tricarboxylic acid, immersing mixture for 5 minutes first in boiling water and then in ice. After addition of 3 cc. of mixture of 10 *N* ammonia and 2 *N* ammonium carbonate, solution is diluted to 50 cc. and red color matched within 5 minutes against standards prepared from potash alum. **Phosphates** are determined colorimetrically by added ammonium molybdate in presence of nitric acid, silicates being accounted for by treating two samples, one with nitric acid immediately before molybdate, the other with nitric acid 1 hour after molybdate.—*W. G. Carey.*

The Determination of Small Quantities of Fluorides in Water. G. BARR and A. L. THOROGOOD. The Analyst, 59: 699, 378–380, June, 1934. Zirconium-alizarin reagent of DE BOER is used and is made by mixing 3 cc. of 3.53 percent aqueous solution of zirconium oxychloride ($8H_2O$) with 1 cc. of 1 percent aqueous sodium alizarin monosulphonate, and diluting to 200 cc. To 50 cc. of sample in Nessler glass are added 2.5 cc. concentrated hydrochloric acid, and just sufficient reagent that very faint pink tinge may remain after 10 minutes; for fluorine contents below 1 p.p.m., 2 cc. of reagent is enough, while for 5 p.p.m, 4 cc. is needed and gives orange color. Color produced is matched against

standards of known sodium fluoride content. When order of concentration is unknown, preliminary estimate of rate of disappearance of pink color is made, using 4 cc. of reagent with standards of 1, 2, 4 and 8 p.p.m. of fluorine. Determination is unaffected by potassium, sodium, and magnesium; but is affected by unusual amounts of calcium, iron, and sulphate; standards of similar composition are made in such event.—*W. G. Carey.*

The Clinical Significance of Traces of Fluorides in Water. N. J. AINSWORTH. The Analyst, 59: 699, 380–382, June, 1934. Water containing 4.5 to 5.5 p.p.m. of fluorine caused "mottled teeth" at Maldon, Essex, in about 90 percent of children born and bred in affected area, mottling being produced at periods when teeth were being formed. Water from unaffected area was free from fluorine. In discussion it was stated that fluorine content was probably not due to infiltration of sea water, as maximum fluorine to chlorine ratio was 170 times as great as that obtaining in sea water. Survey of literature and 9 references are given.—*W. G. Carey.*

The Chlorination of Water Supplies. P. S. LELEAN. Water and Water Engineering, 36: 436, 432–434, July, 1934. Paper read at Annual Meeting of British Waterworks Association, June, 1934. Evolution of modern methods of chlorination and of application of gaseous chlorine are first dealt with. Initial results obtained by RACE for Ottawa are then given, i.e., by combining treatment with 0.13 p.p.m. ammonia and with hypochlorite to yield 0.25 p.p.m. chlorine, reduction of total organisms by 98.9 percent and of *B. coli* 99.6 percent was obtained, which compares well with results from similar treatment of Thames water practised today. Thames water is filtered after ammonia and before chlorine additions, giving greater safety and necessitating smaller chlorine dose than if filtration followed chlorination; but cost of filter washing is increased. For prevention of aftergrowths, chloramination presents an enormous advantage over simple chlorination; explanation offered being that chloramine gives off its loosely attached chlorine (some 10 percent) within one to five hours and thereafter yields its "structural" chlorine slowly and only as needed to destroy organisms. Other advantages are that less chlorine is required than for simple chlorination because it is not wasted; neither taste nor odor is caused; and, because chloramine is stable below 80°C, less chlorine is evolved from hot water systems. Potassium permanganate is less economical form of treatment than ammonia-chlorine.—*W. G. Carey.*

Some Fundamental Facts on Base Exchange. G. AUSTERWEIL. Chemistry and Industry, 53: 25, 185 T–189 T, June 22, 1934. Chief reaction between cation in aqueous solution and zeolite is governed by extraction laws, the base-exchanger having function of a solid solvent non-miscible with liquid solution of exchanging base. Reaction is independent of concentration, is reversible, and is limited and governed by law of mass action and by phase rule. Side reactions may also occur between more basic zeolites and heavy metal cations which are partly precipitated as oxides or hydroxides, or which enter into the anionic portion of the base-exchanging molecule, displacing aluminium therefrom. For ordinary good commercial zeolites, time factor for equilibrium

between two strongly basic cations, one as mobile cation of zeolite, other in aqueous solution as salt, is 30 minutes. Certain amount of importance is attributable to viscosity of reacting cationic solutions, for reactions are carried out at surface of capillary channels as well as at surface of mass.—*W. G. Carey.*

Water Pipe Services Thawed for $10. Electrical World, 104: 8, 232–3, August 25, 1934. Speaking before group of utility engineers, H. C. HAMILTON, superintendent of Boston Ill. Co.'s testing department, stated that in answer to city water department's appeal for help, three pipe-thawing outfits were mounted on trucks and put to work. Each consisted of (1) 200-amp.-hr. electric vehicle battery, (2) 10-kva booster transformer, with primary winding of 110 or 220 v., while secondary winding of 20 v. was used with a 2.5-kw. regulator, (3) a 36-kva., 2300 to 230 or 115 v. regulator, which was used as a variable voltage transformer, excited from one phase of an overhead or underground distribution circuit. It is necessary to disconnect entrance pipe in basement and all ground wires must be removed from water pipe as precautions. Short table shows that 240 amps. applied to a ¾-inch service will thaw it in 16.5 minutes. Thawings numbered 165. Best thawing outfit is undoubtedly direct current generator, similar to some welding outfits.—*R. H. Oppermann.*

Review of Cathodic Protection of Pipe Line. A. F. BRIDGE. Paper presented before American Gas Association Convention, Atlantic City, N. J., November 1934. Knowledge of underlying theory, as fully presented in several recent papers, is assumed. Ultimate success, economically, of this method depends on answers to three fundamental questions which are discussed, namely, (1) Does electrical drainage effectively prevent soil corrosion of metallic substructures? (2) Will application of potential, with resultant current flow, shorten or prolong the useful life of pipe coatings? and (3) Will electrital resistance of pipe coatings decline, due to water absorption or mechanical breakdown, until increasing energy costs make continued drainage prohibitive? and, if so, how rapidly will decline proceed? Examples are given of calculations required in determining economic feasibility of drainage project. It has been demonstrated that negative potential of 0.2 volt (net), pipe to soil, will effectively prevent corrosion. Success of cathodic protection projects frequently depends on preventing continued deterioration of coating after drainage is applied. While experience to date indicates that for coatings several years old when drainage is started and which have therefore reached equilibrium in water absorption, deterioration is arrested by drainage, evidence is still meager and therefore inconclusive.—*R. H. Oppermann.*

Quality of Piped Water Unimpaired by Grounding. H. S. WARREN. Electrical World, 104: 3, 81, July 21, 1934. Protective grounding in accordance with the National Electrical Code is not believed to affect water in pipes concerned. Computation is given of leakage of direct current from pipe to water and comparison made with galvanic couple. Even assuming any significant leakage of current through water, worst that could happen would be that a very small part might be decomposed into oxygen and hydrogen gases; which should not injure remainder of water.—*R. H. Oppermann.*

Laying a Huge Pipe Line in Rugged Country. O. L. SNYDER. Compressed Air Magazine, 39: 2, 4348–50, February, 1934. Article describes construction of conduit between Bouquet Canyon Reservoir and Owens Valley Aqueduct for water supply of Los Angeles, Calif. Crossing of precipitous valleys necessitated use of pipe sections weighing up to 9 tons each, on hills having slopes as high as 76°. Conduit is 4½ miles long, and at lowest point will be under maximum static head of 820 feet. Where pressure will be greatest, pipe has wall thickness of 1.625 inches and diameter of 80 inches. Where head will be only 200 feet, wall thickness is 0.375 inch and diameter is 94 inches. Diameter and wall thicknesses vary between these extremes.—*R. H. Oppermann.*

Review of Work on Pipe Coatings and Corrosion for 1934. SCOTT EWING. Paper presented before American Gas Association Convention, Atlantic City, N. J., November, 1934. Economical way to reduce corrosion losses on transmission system might be summarized thus: (1) use good coatings; but do not coat everything, because in many soils it is unnecessary; (2) expect to repair leaks and to recondition parts of the line; and (3) make soil corrosiveness surveys. Results of questionnaire regarding services bring agreement that something should be done to prevent corrosion near cellar walls. General opinion is that services should be coated. Service replacement records should be kept.—*R. H. Oppermann.*

Welded-Arch Pipe for Water Supply. Engineering, 138: 100, July 27, 1934. Pipe supplying potable water to Lausanne, Switzerland, had to be carried across unstable ground consisting of clayey calcareous marl and mud, in which constant movements occur and which extends to considerable depth. In order to avoid risk of rupture, an arch pipe was constructed. Pipe is 19.7 inches in diameter and normal flow is 2860 gallons per minute. Span of arch is 137.8 feet and rise, 22.97 feet. Arch was designed with fixed abutments, which are reinforced concrete monoliths. The plates of which arch is constructed are 0.47 inch and 0.59 inch thick and 1 meter long.—*R. H. Oppermann.*

The Production of Sulphuretted Hydrogen in the Slow Sand Filters at the Madras Waterworks. B. B. DEY and S. V. GANAPATI. Reprint, Water and Water Eng., 36: 430, 107–11, March, 1934, and 432, 229–31, April, 1934. Within year after opening of Madras filter plant in 1914, hydrogen sulfide was noticed in stored filtered water, together with colorless gelatinous growths in long trailing filaments. Nine investigations of problem have been conducted since that date. Study described herein was undertaken to determine mechanism of hydrogen sulfide production. Examinations using VAN DELDEN'S medium disclosed presence of sulfate reducing organisms in black slime at bottom of Red Hills Lake (source of supply), in blackened growth of *Plumatella Tangynaikae* (Rouselet) which infests raw water conduit (8 miles long), and in blackened sand found several inches below surface of filters. Study of growth of, and of production of hydrogen sulfide by organisms so obtained in media containing various organic compounds, and experiments on effects of nitrate, sodium chloride, and temperature indicated the only effective agent in sulfate reduction in Madras water to be *Spirillum desulfuricans*, described by BEIJER-

INCK and by VAN DELDEN. Latter's agar medium was found most suitable for isolation of pure cultures. Optimum temperature for sulfate reduction was found to be 28–31°C., marked inhibition occurring below 22° and above 41°. Analyses showed that sulfur content of water (from 20.9 to 24.0 p.p.m. as SO_3, in raw water) was almost wholly in inorganic form. Hydrogen sulfide content of filtered water during one filter run was found to increase from 0.5 to 4.4 p.p.m. in course of 12 days, concurrent reduction in sulfate content being observed, which, however, was not sufficient to account for whole of hydrogen sulfide produced. This is explained by fact that while hydrogen sulfide is produced throughout year, part of it is retained in sand as sulfides in winter months, during which time hydrogen sulfide content of filtered water is lowest, and released by action of carbon dioxide liberated by decomposing organic matter during summer months, when organic content of water is excessive. Rough prefilters have been installed which remove about 7 percent of organic matter and final filters are now operated at 3 times normal rate of 4 inches vertical per hour to prevent creation of anaërobic conditions in sand beds necessary for sulfate reduction. As result, effluent is almost free of hydrogen sulfide, making possible effective chlorination of filtered water. Arrangements are in progress for application of chlorine at entrance to raw water conduit in effort to eliminate growths of *Plumatella*. Bibliography of 18 references.—*R. E. Thompson.*

The Drought of 1933–1934 in Illinois. W. G. POTTER. Bulletin of the Associated State Engineering Societies, **10**: 2, 19, April, 1935. While spoken of as the drought of '33–'34, it should in reality be called the drought of '30–'34. Data are given on annual deficiencies in rainfall from end of 1929 to July 1934 and the observations are also presented graphically. Effects upon stream flow are shown and a distinct lag of low stream flows behind low rainfall records is indicated.—*H. E. Babbitt.*

Pumps; with Special Attention to Water Works Practice. H. P. BINDER. Bulletin of the Associated State Engineering Societies, **9**: 3, 33, July, 1934. In general, three types of energy are available for use in water works pumping stations: electricity, which is applicable to stations requiring 500-h.p. units; internal combustion, for the range 500 to 1,500 h.p.; and steam, for larger units. The centrifugal pump has reduced other types to a very small percentage of modern installations. In recent years, improvements in the efficiencies of centrifugal pumps have been appreciable, and single-stage pumps are now available for heads up to 125 pounds per square inch. Turbine-driven units have shown duties as high as 218 million gallons per day. Synchronous-motor-driven pumps are, however, more common than turbine-driven. Lack of variable speed is a drawback to use of alternating current type equipment: in this respect gas engine drive possesses an advantage. Some general advice concerning factors other than efficiency, to be considered in selection of pumping equipment, is given at close of article.—*H. E. Babbitt.*

Report of the Committee on Sanitary Engineering. Bulletin of the Associated State Engineering Societies, **9**: 3, 36, July, 1934. Progress in sanitary

engineering for the year 1933 is briefly outlined. Interesting trends in water works practice include:—improved appearance of structures; installation of flocculators; new types of mixing to aid coagulation; improved equipment for handling chlorine; use of iron salts in coagulation; increased activity in taste and odor control; water softening; and better laboratory control of purification plant operation. Tabulated financial summary of water works and sewerage projects under the P.W.A. is presented. A detailed résumé of annual report of sanitary engineering division of State Board of Health of Wisconsin is presented, with particular reference to water works accomplishments in that state.—*H. E. Babbitt.*

Underground Corrosion. K. H. LOGAN. Proc. Amer. Soc. Civil Eng., 61: 3, 317, March, 1935. Economic importance of underground corrosion is attested by considerable sums being expended for study of corrosion problems by associations of pipe owners and pipe-owning corporations. Underground pipes in the United States have been estimated at 450,000 miles in length and at nearly 6 billion dollars in value. In the oil industry alone, annual loss due to underground corrosion of pipe lines has been estimated at $25,000,000. Soil corrosion is characterized by its uneven distribution and by the fact that most ferrous pipe materials are attacked at nearly the same rates. The major cause of the corrosion seems to be non-uniformity in the distribution of oxygen and moisture along the surface of the pipe line. Methods suggested for reducing corrosion losses include:—use in pipe of copper and copper alloy, which corrode less rapidly than ferrous materials; increasing thickness of pipe walls; and use of protective coatings. Soil corrosiveness surveys are suggested as a means of improving effectiveness of coatings. In appendix are listed some of more important recent articles on underground corrosion and related subjects.—*H. E. Babbitt.*

Controlling the Tennessee River. A Symposium. Civil Engineering, 5: 4, 199. April, 1935. T.V.A. projects involve several dams, three of which are under construction. **A Complicated Problem of Regulation.** J. S. BOWMAN. For almost a century, the possibility of using the Tennessee and its tributaries has been repeatedly investigated. Projects proposed and constructed from time to time indicate the vital interest in this problem. Consideration of the basin as a whole is important for an understanding of the individual projects. Roughly, the drainage basin may be visualized as a huge crescent facing northward. Near the center of crescent, its average width of 110 miles is reduced to 40 miles by a constriction 50 miles long. Eastern half lies in broken and mountainous region of high precipitation and steep slopes; whereas western half has low relief and flat gradients, except at Muscle Shoals, and tributaries there are long and sluggish. Precipitation in the basin varies on account of differences in elevation, shielding effect of mountain ranges, and passing of different storm tracks over the east and west parts. It ranges from 75 inches in the Appalachians to 50 inches in the lower valley. In general, the problems of control involve conflicting interests which cannot be reconciled. Under the proposed plan, power generation and flood control are favored by the construction of three dams, Norris, Wheeler, and Pickwick. **Design and Construc-**

tion of Wheeler Dam. W. M. HALL. Brief historical résumé of events leading up to the construction of this dam is first given. Project will be a run-of-the-river development, designed to improve navigation and to generate power. Total reservoir capacity will be 1,085,000 acre-feet. Continuous power capacity at dam will range between 12,000 and 24,000 kw. Project embraces a single navigation lock, gravity type dam, and power-house. Over-all length of structure will be about 6,400 feet. Lake thus formed will have an area of approximately 100 square miles and will extend up the river for more than 80 miles. Of out-door type, power-house will have no housing over the cranes, and generators will be protected from weather by removable metal covers. The turbines, only one of which will now be built, will have a rating of 45,000 h.p. each, under an effective head of 48 feet. Foundation of the dam consists of a series of sedimentary beds lying nearly horizontal, chiefly composed of cherty and siliceous rock alternating with layers of very fossiliferous and almost pure limestone, as revealed by investigations carried out by the War Department at various times. All foundations are being grouted under both low and high pressure. Concrete field laboratory has been equipped with all the necessary testing apparatus to keep control of proportioning, cement consumption, and strength. It is expected that major part of work of excavation and of placing of concrete will be completed within next 18 months, and that entire undertaking will be completed within two years. **Design of Norris Dam and Power House.** B. M. JONES. As early as 1911, present site of Norris Dam was investigated by power interests. The U. S. Corps of Engineers commenced final surveys in April 1933 and in same month turned their plans and data over to the TVA, which has assumed control. Comparative investigation of four possible types of dam showed that straight gravity type would cost the least. Article then goes into detail with regard to design assumptions, working stresses, and material quantities. Temperatures of the foundation and of interior of dam will be recorded by resistance thermometers. Near-by quarry of hard dolomite furnishes all the concrete aggregate. No cut-off wall is being used, because of extensive grouting of the foundation. Energy in water passing over spillway will be dissipated in hydraulic jump. There will be two generating units in the power-house, each turbine being designed to develop 60,000 h.p. at net head of 180 feet. Work on coffer dams was commenced on November 7, 1933 and up to February 1, 1935, 380,000 cubic yards of concrete had been placed.—*H. E. Babbitt.*

Devices for Measuring Water. A Symposium. Civil Engineering, 5:4, 218, April, 1935. Development of new instruments and improvement of old ones. **Ten-Foot Weir and Venturi Meter Compared.** C. M. ALLEN and L. J. HOOPER. Calibrations are made and recorded graphically, of a 36-x 16-inch Venturi meter, and a 10-foot contracted weir, by means of a weighing tank. The coefficients of the meter varied from 0.976 to 0.954, with no error greater than 0.25 percent. The weir gave measurements within 2 percent under a wide range of conditions, but with errors up to 15 percent obviously possible. Careful calibration of the two devices, under conditions of use, is essential for precision in measurements. **The Pitot Tube in Current Practice.** E. S. COLE. Problems involved in use of Pitot tube include:—means for inserting the tube into

pipe under pressure; type of orifice giving consistent readings; differential manometer; method of integrating flow from velocity traverse; frictionless recording of manometer deflections; and means for calibrating the instrument. Device is excellent for measuring flow of water in pipes under pressure and in hands of experienced men will give results correct to 0.5 percent. A simple calibration curve is shown. **The Bentzel Velocity Tube.** F. H. FALKNER. This instrument for measurement of velocity of flow in open channels consists essentially of a U-tube with both ends turned through 90 degrees, a tapered glass tube in the downstream leg, a priming device, and a float in the tapered section. In operation, the device is filled with water, somewhat as a siphon, and flow through the tube is caused by velocity of impingement against open up-stream end. This in turn affects the position of the float, by observing which, velocity is measured. Instrument is accurate up to within 1 or 2 percent.—*H. E. Babbitt.*

Joint Water Works System for Six Illinois Towns Financed by PWA. Anon. Cast Iron Pipe News, 1:2, 4, April, 1935. The "Six-Town" project is a single system, furnishing water from a single source, the city of Springfield, to six other towns with combined population of 10,000, the most remote being Girard, 25 miles from Springfield. The contract called for each town in turn to purchase water from its neighbor nearer to Springfield; thus Auburn purchases from Springfield, Pawnee from Auburn, etc. Financial arrangements were based on consolidated bond issues of the six individual towns, totalling $796,000. Local workmen, assigned to the work through the National Reemployment Service, were employed. Total wages paid locally approximated $265,000.—*H. E. Babbitt.*

Water Supply Engineering. Third Report of the Committee of the Sanitary Engineering Division. Proc. Amer. Soc. Civil Eng., 61:4 (part 1), 439. Report includes brief discussions of following topics.— Cement and concrete with respect to the prevention of high setting temperatures; Caisson core walls for dams; Extra large coarse aggregate in concrete of dams; Pumping concrete; Earth dams; Cement mortar lining for pipe lines in situ; Measurement of tastes and odors in water; Elimination of tastes and odors in water supplies; Sterilization of water; Effect of weeds on taste of water and control of weed growth; Coagulants for water purification, and their application; Prevention of corrosion in pipes by treatment of water; Frozen pipes; Water hammer problems; Friction coefficients in distribution systems; Friction loss in bends; and Progress of committees.—*H. E. Babbitt.*

Epidemiology of Amebiasis. J. C. GEIGER, G. H. BECKER, and J. P. GRAY. Am. Jour. Pub. Health, 25:4, 389, April, 1935. Epidemiology or amebiasis has become a source of intense public interest in light of 1933 experience in Chicago. Any casual study of Chicago data forces attention upon plumbing and cross-connections. Water, or uncooked foods, can transmit the disease only when contaminated with fecal matter containing resistant encysted entameba. Among the various sources of infection may be listed: entrance of contaminated water into the mouth, either in eating, drinking, or bathing; or into the rectum,

as in the use of enemata; or through raw vegetables used in salads, contaminated by washing with polluted water. *E. histolytica* cysts are removed from water by coagulation and filtration. The chlorine concentration required to kill the cysts is much more than could be used in a public water supply. The Chicago experience may be repeated in other localities and it is not inconceivable that conditions of siphonage and cross-connections between sewer and water systems, as found in Chicago, can be duplicated in many other communities.—*H. E. Babbitt.*

Potability of Water from the Standpoint of Fluorine Content. H. V. SMITH. Am. Jour. of Public Health, **25**: 4, 434, April, 1935. It was not until 1931 that mottled enamel was found to be due to fluorine in water. Lack of accurate methods of fluorine analysis has impeded progress in determining the toxic level. The FAIRCHILD method was finally selected, in which ferric iron in excess is added to the fluorine-containing water and the uncombined iron is then determined iodimetrically. Analyses of many waters for fluorine, using various methods, have been made and compared, as shown in table. It is concluded that concentration of 0.8 to 0.9 p.p.m. of fluorine in drinking water will cause mottled enamel in children of susceptible age. Experimental work has shown the FOSTER method to be satisfactory for determination of fluorine in waters which have been treated with aluminum sulphate for fluorine removal, if considerable aluminum remains in solution.—*H. E. Babbitt.*

Sanitation and Conservation of Illinois Surface and Underground Waters. C. E. SCHWOB. Journal of the Western Society of Engineers, **40**: 1, 9, February, 1935. Account is given of developments which led to present state organization for control of stream pollution. Recent accomplishments of the Sanitary Water Board are recounted.—*H. E. Babbitt.*

Journal of the New England Water Works Association, Vol. 48, No. 2, June 1934. The Cobble Mountain Power Tunnel. HARRY H. HATCH. 123–146. Cobble Mountain development, combined water-supply and water-power project for Springfield, Mass., includes construction of highest hydraulic fill dam in world, despite tributary watershed of but 46 square miles, yielding average flow of 90 c.f.s. Fall of head averages 420 feet. Power house and tunnel have capacity 10 times mean flow of stream. Income of $270,000 annually for 30 years from Turner Falls Power and Electric Co. made 6-million-dollar project financially possible without jeopardizing water supply purposes. Present article of series describes 6,376-foot, concrete-lined, horseshoe-shaped power tunnel, 10 feet by 9 feet 4 inches, from intakes and gate house to 450-foot circular 10-foot steel-lined section extending through surge tank above power house. Broome self-inclosing sluice-gate, 12 feet wide by 13 feet high, weighing 15 tons, is operated by Philips and Davies 200-ton electric-driven double drum hoist, and in access shaft is 12-inch bypass valve to fill outlet side of tunnel (power house side), to equalize pressure so that gate may be easily raised. Tunnel line and grade were so carefully controlled that error in meeting of headings was but 0.1 foot in alignment and grade. Most of excavation was through solid rock, mica schist with narrow veins of gneiss and some Williams-

burg granite. Rock was drilled and shot with dynamite, 7 pounds being used per cubic yard of excavation. Mucking machines dumped spoil into 1-yard cars, pulled in 4 to 6 car trains by electric dinkey (narrow gauge). Pantograph sections of bore were taken every 25 feet. Grouting under pressure up to 150 pounds was resorted to where running water, seams, and mud pockets were encountered. After concreting, briquettes made daily in field averaged strength of 262 pounds per square inch for 7 days and 357 pounds for 28 days. Compression tests were from 2690 to 3530 pounds for 28 days, with ratio of compressive to tensile of 9.2. Cost of tunnel was $83.70 per linear foot, total expenditure, including gate house and shaft, being $728,522. Bonus system expedited work considerably, while reducing cost. Engineering supervision represented but 5 percent of total expense. **Boston Metropolitan Water Supply Extension.** KARL R. KENNISON. 147–250. Inadequacy of Wachusett and Sudbury Reservoirs and drainage areas for future needs of District led to development of Ware and Swift Rivers with construction in valley of Swift River of Quabbin Reservoir, 18 miles long and holding 415 billion gallons of water, 6 times capacity of Wachusett. Area is 39 square miles; shore line, 151 miles, including shores of 60 islands. Depth of water at intake is 100 feet making 405 billion gallons available. Tributary will be 186 square miles of Swift R. and 98 square miles of Ware R. drainage areas. Quabbin Reservoir will supply Wachusett through 24.57-mile tunnel, with flow controlled by gates at Wachusett end. In passing beneath the Ware River, a drop is made into the tunnel, thus making the Ware tributary to Quabbin Reservoir. This project which was started in 1926 and is now half finished led to considerable litigation, including State of Connecticut's bill of complaint to enjoin use of the water by the District. U. S. Supreme Court upheld right of Massachusetts to make diversion, subject to regulations of War Department, which acts to protect navigation on Connecticut River. Diversion is also limited by Massachusetts Legislation. Commission purchased, or took by eminent domain, land for all construction requirements and has to date purchased 5,277 acres above Ware R. intake for watershed protection. Detailed description of construction features of contract work on new dams and dikes and on concrete-lined transmission tunnel are given. Tunnel was driven through compact schist, varying to granite, with timbering necessary only for a few short stretches. Costs, miscellaneous data, and bibliography are included. Discussion covers geology of area, analyses of water from new source, and inventory of physical assets of the Metropolitan District Commission. **Report of N.E.W.W.A. Committee on Hydrant Markings.** 252–3. Hydrants should be tested to determine capacity with residual pressure of 10 pounds per square inch. All barrels shall be painted chrome yellow for visibility, with nozzle and cap of distinguishing color to indicate capacity, viz.:—

	Indicated Capacity Gallons per minute
Class A, green	1,000, or more
Class B, yellow	500, or more
Class C, red	Less than 500

Suggestion is made that capacity in excess of 2,000 g.p.m. be plainly marked on barrel.—*T. F. Donahue.*

Journal of the New England Water Works Association, Vol. 48, No. 3, September 1934. **Some Phases of Southern New England Hydrology.** Discussion of Paper by CALEB MILLS SAVILLE. 255–271. Periodic inspections of rain-gauges by competent engineer are essential to accurate results. Probability curves to predict rainfall require an accurate "statistical" sample. Comparison of a single rain gauge record in a large area with runoff from same area, scientifically measured and carefully computed, is illusory. Table of minimum discharge in second-feet of selected rivers of U. S. is given. **Reforestation of North Adams, Mass., Watersheds.** JOHN P. MILLER. 272–274. From 1921 to 1933, 340,000 evergreen trees donated by State Forestry Division were planted. Annual inspection of area is made to remove wild currant and gooseberry bushes, sources of blister rust which attacks white pine. Planting tends to prevent soil erosion and turbid water, reduces silting of reservoirs, and prolongs runoff. Replacing deciduous trees with evergreens reduces color. **Development of the Manchester, New Hampshire, Water Works.** J. H. READ. 275–280. Development traced from 1844, when source, Massabesic Lake, was first proposed, to present municipally owned project. Low-lift pumping station supplying distribution reservoir was originally equipped with water turbine and upright pumps. In 1886 turbine was replaced by 36-inch Risdon water wheel, and upright pumps supplemented by addition of Davidson 5-m.g.d. duplex. High service system with two 5-m.g.d. steam Worthington pumps was installed in 1893. Present population is 78,000; consumption 4.84 m.g.d. Pumps in both low-lift and high-pressure plants are now motor-driven centrifugal. New high service reservoir, of 17-m.g.d. capacity, is under construction. **Manchester's New Distribution Reservoir.** PERCY A. SHAW. 281–285. Low-lift pumping station supplies water from L. Massabesic to 16-m.g. distribution reservoir for low service consumption of 2.8-m.g.d., and to 3.5-m.g. reservoir for high service consumption of 2.1 m.g.d. Inadequacy of high service reservoir for fire protection purposes led to construction of 17-m.g. reservoir on Oak Hill. Project required 30,000 cubic yards earth cut and 20,000 cubic yards rock cut. **Historical Sketch of the Winchester, Massachusetts, Water Works, 1873–1933.** E. C. SANDERSON. 286–299. Water works now consists of three reservoirs, North and South reservoirs supplying sections of the town, and Middle reservoir, a storage basin and two electrically operated pumping stations. Of 614 acres of watershed, town owns 247. **Deterioration of Water Pipes in Belmont, Massachusetts, Resulting from Tuberculation.** CHARLES W. SHERMAN. 300–305. Since 1898, water has been supplied by Metropolitan District of Boston. Experience has demonstrated that pipes conveying this soft, upland water tuberculate rapidly. Chlorination, practised for three years, is only treatment. HAZEN-WILLIAMS coefficient C for various pipes when new were estimated, present values for same determined, and percent capacity calculated. Flow was controlled by pitometers in pipe, by hydrant pitots, and by Venturi meter charts. Unlined cast iron pipe (pit cast) after 46 years service showed 37 percent capacity ($C = 46$), while similar pipe cleaned one year previous to test gave 62 percent ($C = 77$). Cement lined pipe after 5 years retained 94 percent ($C = 122$) of original capacity. Tests made in July 1934 on 3,000 feet of 10-inch pipe give the following inter-

esting comparative results, rate of flow being 2.07 m.g.d. and velocity, 5.86 feet per second:—

SECTION NO.	PIPE	AGE	LENGTH	PRESSURE DROP	VALUE OF C
		years	*feet*	*pounds per inch²*	
1	Unlined C.I.	7	540	6.4	83
2	Unlined C.I.	10	910	20.4	63
3	Cement-lined	6	1690	9.6	121

Value of C for cement lined pipe was consistent with previous tests on 6- and 8-inch sizes. For unlined C. I. pipe, coefficients were lower than anticipated. **Sanitation of Watersheds.** A. D. WESTON. 306–313. General Laws of Massachusetts protect public water supplies by forbidding discharge of sewage within 20 miles of filter gallery or intake. Fine of $10 is provided for bathing in domestic water supply. Exception is taken to Engineering Section Committee report to A.P.H.A. in October 1927 that swimming is of little importance as a source of dangerous pollution and that water departments should protect their own water supplies. Author feels that greatest good will derive from restricting reservoir to one function. **Pipe Thawing by Electricity.** H. C. HAMILTON. 314–319. Description of outfits used to thaw frozen service pipes in Boston during winter 1933–34. (1) Battery from electrical vehicle, 4 blocks of 8 cells each, 800 ampere-hour capacity at 16 volts, equipped with suitable leads, etc. (2) Booster transformer of 10-k.v.a. capacity, with primary winding of 110–220 volts and secondary winding of 20 volts with 2½-kw. regulator: house current (115 volt service) was utilized. (3) 36-k.v.a. regulator, from 2300 to 230 or 115 volts, used as variable voltage transformer, being excited from one phase of an overhead or underground distribution circuit. Most efficient type of water pipe thawer would be d.c. generator of 400–500 amperes capacity at 115 volts similar to portable welding outfit. In thawing, one end of circuit is attached to entrance pipe in basement, other end to hydrant or entrance valve. For precaution against fires, ground wires were removed. Average total charge for thawing service was $10. **Cold Weather Troubles.** A Symposium, March 21, 1934. 320–344. Experiences of various water works officials in thawing frozen mains and service pipes, with suggestions for minimizing difficulties encountered. **The Corrosion Problem.** HAROLD C. CHANDLER. 345–349. Lime treatment is most effective and economical method of corrosion prevention. If pH is maintained at or above point of solubility equilibrium of calcium carbonate, impervious coating of $CaCO_3$ will be formed in distribution system, thereby reducing corrosion to minimum. Cement lined pipe supplemented by lime treatment is solution to dead end problem. **Electrical Grounds on Water Pipes.** H. S. WARREN. 350–371. Obvious advantages of using water pipe for ground has led to widespread use in electrical field. Direct current, as from trolley railway, may cause pitting due to electrolysis where current passes from pipe directly to earth by electrolytic conduction. This will not occur if current continues along pipe until taken out through metallic path. Railway electrification with 25-cycle alternating current has no corro-

sive effect upon underground water pipes. That stray currents should affect quality of water is improbable, due to its low conductivity. Distilled water is practically a non-conductor. Tests indicate that galvanic couple will introduce more current into water than current passing along pipe. Since 1913, grounding is mandatory by National Electric Code on circuits less than 150 volts, to reduce electrical hazards in buildings. Participants in **discussion** disagree emphatically with author's views, citing cases of metallic and astringent odors, of discoloration of water, and of deterioration of pipes, all attributed to use of water pipes for ground.—*T. F. Donahue.*

NEW BOOKS

Papers, First Annual Arkansas Water Works Conference, Fayetteville, Arkansas. February 18–20, 1931. General Extension Service, Univ. of Ark., Fayetteville. 6 x 9 inches. 51 pp. **History of Public Water Supply.** G. P. STOCKER. 6–14. Sources, means of collection, treatment, pumping, and distribution traced from early ages to present. **Distribution Systems.** W. L. WINTERS. 14–23. Discussion of design, construction, records, and maintenance. **Fuel Economy in the Boiler Room.** J. T. STRATE. 23–29. Composition of coal, principles of combustion, and means of reducing boiler losses. **Bacteria in Water and their Significance.** W. L. BLEECKER. 29–33. Good elementary discussion. **Pump and Engine Maintenance.** H. E. NUNN. 33, 34. **The Care and Operation of Filters.** A. H. ULLRICH. 34–38. Successful performance depends upon preliminary preparation of water and careful maintenance. **Economics of Purification Plant Operation.** L. A. JACKSON. 38–42. Frequent sampling and analyses, and close scrutiny of performance of processes of sedimentation, coagulation, filtration, and sterilization point way to economies in cost of operation. **The Problems of the Distribution of Water for Fire Protection.** G. D. SUTER. 42–45. Application of N.B.F.U. standard grading schedule to distribution systems in Arkansas. **Problems in Water Plant Operation.** E. M. RATLIFF. 46–51. Producing an adequate and safe supply, selling the supply to the consumer, and financing plant extensions.—*R. L. McNamee.*

Papers, Second Annual Arkansas Water Works Conference, Fayetteville, Arkansas, February 17–19, 1932. General Extension Service, Univ. of Ark., Fayetteville. 11 x 8 inches. Mimeo. 75 pp. **Engineering Extension.** W. N. GLADSON. 7, 8. **Filtration of Water.** O. M. SMITH. 8–14. Explanation of the functioning of a rapid sand filter through the factors of straining, adsorption, electrolytic changes, and biological growths. Discussion of various theories of the causes of filter troubles due to sand settlement, cracks, and mudballs. **Water for Industrial Purposes.** R. G. PADDOCK. 14–17. Impurities in natural waters causing caustic embrittlement, priming, and foaming. Means of reduction of impurities and of removal of organic matter from cooling surfaces of steam condensers. **Pumping Plant Economies.** L. A. JACKSON. 17–24. Coal should be bought on analysis. Boilers should be carefully fired, constantly checked for air leaks, and kept free of scale and soot. Steam should be clean and steam leaks stopped. Pumps should be checked

for suction leaks and slippage. Careful and accurate records are helpful in locating and eliminating inefficient plant units and operating practices. **Pumping Plant Economies (Motor).** R. R. PITMAN. 24, 25. Centrifugal pumps, having fixed characteristics, should be carefully selected for the service desired. **Electrical Losses in Electrically Driven Pumping Plants.** W. B. STELZNER. 26–37. Motor losses are usually due to improper technique in starting, motor speeds, or capacity, unsuited to pump speeds or capacity, poor power factor conditions, or voltage above or below rated values. Discussion points out types of motors suited to various types of pumps. **Pollution Hazards of Ground Water Supplies.** FRED PUCKHABER. 32–37. Location of source with respect to known pollution, cross-connections, inadequate protection at well head, and corroded casing are likely points of danger. Sterilization of well supplies is recommended. **Water Waste Reduction by Metering.** E. S. SMITH. 37–39. **Leakage and Unaccounted for Water.** E. M. RATLIFF. 39–46. Study at Fayetteville indicates that 30 percent of water pumped is lost, or under-registered by meters. Of this amount, about 41 percent is classed as under-registered. **Distribution Losses Due to Pipe Friction.** G. D. SUTER. 47–49. Periodical friction flow tests indicate places where distribution system needs reinforcement, discover closed valves, or other obstructions, and reduce pumping costs by reducing friction. **Water Waste Surveys.** A. E. SPINNEE. 49–52. Description of procedure in making pitometer waste survey. **Waste of Chemicals in Water Treatment.** HARRISON HALE. 52–56. Laboratory control of application of chemicals saves in chemical costs, more than cost of laboratory supervision. **Tastes and Odors in Arkansas Public Water Supplies.** M. Z. BAIR. 56, 57. Low stream flows and high temperatures in 1930–31 resulted in decomposition of algal and other organic matter, causing tastes and odors, for removal of which activated carbon and prechlorination have been generally satisfactory. **Dominick-Lauter Medium Compared with Standard Lactose Broth for the Determination of B. Coli in Water.** H. V. STEWART. 58–60. D.-L. medium does not show gas formation in presence of any gas-forming organisms except *B. coli*. It has two advantages: speed and partial confirmation by use of organic stains. In no case did standard method show *B. coli* without result being confirmed by D.-L. medium, whereas D.-L. medium showed *B. coli*, while standard medium, though showing 50 percent gas, failed to confirm on endo agar. Continuation of study is recommended. **Cost Accounting and Records for Water Works.** LOYD REBSAMEN. 60–69. Schedules for capital and operating accounts. **Office Records and Machine Billing.** H. E. REIMAN. 69–75. Advantages of machine billing explained.—*R. L. McNamee.*

Papers, Third Annual Arkansas Water Works Conference, Little Rock, Arkansas, February 22–25, 1933. General Extension Service, Univ. of Ark., Fayetteville. 11 x 8½ inches. 69 pp. **Water Softening.** E. L. FILBY. 9–14. Of 76 Arkansas cities of over 1500 population, 37 have water supplies of less than 85 p.p.m. hardness and only 15 of over 150 p.p.m., hardest being 364 p.p.m. and softest, 8 p.p.m. The 2-m.g.d. plant at Neodesha, Kan., consists of several small impounding reservoirs, with chemical feeding equipment, mixing tanks operated by compressed air, clarifiers, settling and carbonation basins

remodelled from existing basins, and two 1-m.g.d. rapid sand filter units, built at cost of $68,000. Raw water hardness of 242 p.p.m., is reduced to 80 p.p.m. at chemical cost of 1.11 cents per 1000 gallons. Operation cost of former plant was 4.3 cents per 1000 gallons; that of new plant, including softening, is 5.21 cents. Average small householder's bill was increased by $9.00 per year. Savings in soap alone, resulting from softening, have equaled the increased cost in certain homes where accurate records were kept and it seems reasonable that, on the average, at least half of the increased cost is saved. The Clarksville iron removal and softening plant is also described. **Problems in Water Plant Operation.** E. M. RATLIFF. 14–20. Public relations problems of water plant operator include collection of accounts, fire protection services to municipality at large, maintenance of meters, and regulation by state health departments. **Selling Your Product and Yourself to Your Consumers.** J. P. HARRIS. 20–30. Development of publicity through newspaper articles, direct mail advertising, public speaking, and open house water plants. **Standard Administrative Bodies.** W. H. VAUGHAN, D. Y. MCDOWELL, and E. V. LEVERETT. 30–35. Discussion of the organization and authority of governing bodies of municipal utilities in Arkansas. **Water Main Cleaning.** W. L. WINTERS. 35–39. Procedure and resulting benefits in cleaning mains by turbine propelled through main by water pressure. **Control of the Chemical Treatment of Water.** M. C. NICHOLS. 39–46. Chemical impurities in natural waters, standards of limiting values for certain impurities, coagulants and softening reagents employed for the reduction of dissolved and suspended mineral constituents, and important principles in the feeding and mixing of applied chemicals. **Treatment of Water Prior to Filtration.** W. DONALDSON. 47–50. Well planned and effective use of coagulant chemicals and of mixing and flocculation processes in preparation of applied water greatly enlarges range of efficiency of rapid sand filters on waters of varied character. **Chemical Stabilization of Sewage.** HARRISON HALE. 50–54. **Progress in Sewage Treatment.** M. C. NICHOLS. 54–58. **Sewage Treatment.** PAUL HANSEN. 58–62. **Stream Pollution.** W. R. SPENCER. 63–69.—*R. L. McNamee.*

Papers, Fourth Annual Arkansas Water Works Conference, Fayetteville, Arkansas, April 25–27, 1934. General Extension Service, Univ. of Ark., Fayetteville. 11 x 8½ inches. Mimeo. 60 pp. **A Survey of Arkansas Water Systems.** GEORGE SUTER. 6–9. Notes on comparative study of water systems of state as fire defense facilities. **The Service of Water Plants to a Community.** L. A. JACKSON. 9–11. Water supply is indispensable service to urban areas and utility providing it is public servant of the highest order. **Water Rates and City Finance in Some Arkansas Cities.** H. W. BLALOCK. 11–14. Water rates should be determined to return cost of service rendered, and should neither require subsidy from tax funds, nor produce excess funds to be expended on general municipal projects not related to water supply. **Selection of Source of Water Supply.** M. Z. BAIR. 14–17. Water supplies must be adequate in quantity and satisfactory in quality; for determination of which, thorough preliminary investigation must be made. **A B C of Plant Operation.** W. L. WINTERS. 17–25. Discussion of personnel, operation and maintenance, and plant records and finances, as important factors in management.

Meter Records. R. C. DOHE. 25–28. Graphical analysis showing monthly records of total revenue, percentage of services billed at minimum rates, and average revenue per service indicates existence of stopped and sluggish meters and directs attention to need for repairs. **The Study of Water Resources of Arkansas.** J. H. GARDINER. 28–32. Description of work of U. S. Geological Survey in gauging and recording quantity and quality of underground and surface waters of the state. **Electrical Pumping Equipment.** R. P. JOHNSON. 32–37. Discussion of suitability of squirrel-cage and synchronous motors, of full- and reduced-voltage starters, and of automatic control for water pumping units. **Internal Combustion Engines.** GERRY BADER. 37–45. Discussion of field of application of Diesel engines in water works service, their characteristics, and cost of power produced. **The Comparative Economy of Power Units for Pumping Water.** L. C. PRICE. 46–52. Hypothetical analysis based on average conditions indicates average pumping costs, including fixed charges, labor, and fuel or energy, as follows (expressed as dollars per m.g.):—

	CAPACITY OF PLANT				
H.P.	900	200	120	60	10
PUMPAGE, M.G.D.	12	2.5	1.0	0.5	0.08
	dollars	*dollars*	*dollars*	*dollars*	*dollars*
Power type:					
Steam	12.50	26.60	45.20		
Diesel	11.36	16.04	23.40	28.70	
Semi-Diesel				27.50	65.00
Gas		15.12	22.30	26.40	62.50
Electricity	25.20	29.50	33.10	33.40	40.30

Ferric Chloride Treatment of Sewage. A. E. GRIFFEN and E. W. SCHOUTEN. 52–56. **Practical Operation of Small Sewage Treatment Plants.** E. L. FILBY. 56–60.—*R. L. McNamee.*

Report of the Water Pollution Research Board (England) for Year Ending 30 June 1934. 44 pp. H. M. Stationery Office, Adastral House, London. No serious outbreaks of water-borne disease occurred in year under review, but exceptional weather conditions caused anxiety, first half of 1934 being particularly dry. "Exceptional Shortage Act" makes provision for meeting shortage difficulties, e.g., suspension, or modification, of compensation water discharge, authorization of water undertakers to prohibit, or limit, use of water, etc. Investigations in progress are described in report, such being base-exchange water softening processes, contamination of water by lead, milk factory effluents, biological oxidation of fats and soaps, tests for biochemical oxygen demand, sewage treatment, and investigation and survey of Rivers Mersey and Tees.—*W. G. Carey.*

The Action of Water on Lead with Special Reference to the Supply of Drinking Water. H. INGLESON. Water Pollution Research Technical Paper No. 4.

H. M. Stationery Office, Adastral House, London. 115 pp. 2 shillings net. Summary of existing knowledge of action of water on lead. Diagnosis of plumbism and its difficulties, numerous opinions as to permissible lead content of water, protection against plumbism, e.g., various filters, treatment of water, and substitution of lead for other metals are first dealt with. Methods of determination of lead and their errors; action of lead on distilled water containing carbon dioxide and oxygen, as well as on water containing acids and nitrates, nitrites, chlorides, sulphates, carbonates, and bicarbonates of various metals; electrolytic action and electrical current leakage are all treated exhaustively. Factors influencing results in experimental determinations, e.g., colloids, light, temperature, aëration, solution of materials from glass vessels, and preparation of specimens are then dealt with. Some 23 outbreaks of plumbism and protective measures adopted; acidity correction; and insoluble substances formed in lead pipes are also discussed. This valuable work concludes with a summary and a bibliography of 371 references.—*W. G. Carey.*

Metropolitan Water Board (London) 28th Chemical and Bacteriological Report for Year Ending December 31st, 1933. R. B. Floris. 28 pp. P. S. King & Son, Great Smith Street, Westminster, London. 10 shillings and sixpence. Average daily consumption was 295.1 million gallons. Routine samples examined were 12,718 bacteriological and 4,541 chemical. Where chlorination, preceded by ammonia treatment, was practised after filtration, percentage of samples free from *B. coli* in 100 cc. was 99.1 at Sunbury, 97.6 at Kempton Park, 96.7 at Walton, 95.9 at West Middlesex, and 90.7 at Southwark and Vauxhall. Chlorine dosage varied from 0.2 to 0.3 p.p.m. and ammonia (as nitrogen) was usually 0.1 p.p.m. Avoidance of chlorination taste troubles was most successful; some success attended control of chironomus fly by spraying shallow marginal areas of Littleton reservoir with paraffin oil, no taste being imparted to water. Algal growths caused some filtration troubles, but serious blocking of filters was less than in many past years. Littleton reservoir banks were treated with copper-lime wash, water level being previously lowered. Rainfall in British Isles was 81 percent of average, and deficiency in Thames and Lee valleys was very pronounced; in former, out of total of 22.60 inches only 8.86 inches fell in last six months, and in Lee valley, total was 18.13 inches, of which 7.56 inches fell in last six months. Over England and Wales, year was not so dry as 1921 (70 per cent of average) or 1877 (74 percent of average), comparable years being 1870 (82 percent) and 1893 (83 percent).—*W. G. Carey.*

The Bacteriological Examination of Water Supplies. Report No. 71 on Public Health and Medical Subjects, Ministry of Health. H. M. Stationery Office, Adastral House, London. 38 pp. 9 pence net. Objects of compilation are to describe technique to secure sufficient uniformity in bacteriological examination of water to permit comparison of results from different laboratories, to explain precautions necessary in obtaining and transmitting samples, and to assist in assessing bacteriological results in terms of hygienic quality. Routine examinations recommended are agar counts at 20–21°C. and at 37°C. and coli-aerogenes count, which group is held to include all Gram-negative non-sporing rods capable of fermenting lactose with production of acid and gas,

and of growing aërobically on agar media containing 0.5 percent bile salt. Less frequently, fecal streptococci, *Clostridium welchii*, and specific pathogenic organisms are searched for; ability of streptococcus to grow in MacConkey broth and its resistance to heat are taken advantage of, while milk test, or sulphite-reduction test of W. J. WILSON are used for *Cl. welchii*. Distinction is made between typical fecal *B. coli* and *B. aërogenes*, and presence of former is regarded with greater suspicion than that of latter, which is much less reliable evidence of excremental pollution. Differentiation is made by the indol, methyl red, VOGES-PROSKAUER, and citrate tests. Detailed technique of sampling, diluting, inoculation of bile salt lactose broth, also of pouring, incubation, counting and reporting the results of plates is given. Confirmatory tests are made from neutral-red bile-salt lactose agar plates and the above differential tests from typical colonies are described. Some five pages are devoted to interpretation and application of results and appendices are given on sampling, apparatus, preparation of media, and MCCRADY's tables of probable numbers of coliform organisms. Additional or alternative tests with EIJKMAN's ENDO, and eosin methylene-blue media are described.—*W. G. Carey.*

Sixty-Eighth Annual Report of the Commissioners of Water Works in the City of Erie, Pa., for Year Ending December 31, 1934. 77 pp. Operating and financial statistics are given in detail, together with brief description of works and schedule of water rates. Minimum of difficulty regarding frozen lines was experienced owing to practice of laying outside lines at depth not less than 5 feet below surface. Improvement in industrial consumption and added domestic consumers in outlying sections resulted in increase in revenue, enabling Department again to show addition to surplus ($21,601.16). Daily average consumption was 22.17 million gallons, an increase of 2.4 million gallons over previous year. On basis of population of 120,000 supplied, figures for daily per capita consumption, (*a*) inclusive and (*b*) exclusive of metered industrial and commercial use, were 184.79 and 114.49 gallons, respectively. Cost of collecting, purifying, and delivering water, including depreciation, was $34.47 per million gallons, a decrease of $2.88 compared with 1933. Number of gallons pumped per pound of coal used averaged 361.86. Water to value of $60,223.24 was supplied without cost for municipal purposes, bringing value of water so supplied to date to $1,092,783.07. Plant operating data show, for Chestnut Street and West filter plants respectively, following amounts of chemicals and wash water used: alum, 0.215 and 0.217 grain per gallon; chlorine, 1.72 and 1.61 pounds per million gallons; ammonia (Chestnut Street only), 1.04 pounds per million gallons; wash water, 2.49 and 1.51 percent of water filtered. Analytical data include monthly average bacterial counts, turbidity, alkalinity, and color of raw and filtered waters, average temperature, and results of *B. coli* tests. Filter effluents of both plants were consistently negative for *B. coli* in 10 cc. and 1 cc. throughout year.—*R. E. Thompson.*

Annual Report of the Bureau of Sanitary Engineering of the Maryland State Department of Health, Year 1934. ABEL WOLMAN. 20 pp. Extensive activities of Bureau during 1934 are reviewed in some detail. Percentage of population served by public water systems is now 73.5, 69.8 percent being supplied

with treated water. Public sewerage systems serve 67.7 percent of population and sewage of 57 percent is treated, a record surpassing that of any other state. New and proposed works submitted for approval are described and special studies conducted are outlined. Study of internal corrosion of distribution systems was continued. Cumberland supply was found to be aggressive to new mains, but corrosive action decreases with age owing to formation of protective coating, protection being practically complete in less than 10 years. Adoption of chlorine-ammonia treatment at Hagerstown has enabled chlorine residuals to be maintained throughout distribution system with lower chlorine dosage, effecting saving in operating cost. Examination of new zeolite iron removal plant at Rock Hall showed that iron content was reduced from 15 to average of 0.5 p.p.m. Efficiency has since been increased by modification of regeneration process. Iron residuals between 0 and 0.2 p.p.m. are possible by this method. Well supply of La Plata contains relatively high concentrations of iron and manganese, largely as sulfates. During distribution, sulfates are reduced, liberating hydrogen sulfide and throwing iron and manganese oxides into suspension. Experiments showed that iron and manganese could be removed by aëration, treatment with lime, or with lime and ferrous sulfate, and filtration. Operation of Pines-on-Severn iron removal system, which consists of aëration, lime treatment, and filtration, has been improved by placing coke in perforated tray aërators and addition of alum with the lime to improve floc formation. Study of Epping Forest supply showed that aëration, lime treatment, and filtration would correct difficulties due to iron. Experiments at Sparrows Point, where coke tray aëration, lime, sedimentation, and filtration does not satisfactorily remove iron, showed that complete removal could be effected by use of ferric sulfate as coagulant or by chlorination after aëration and prior to lime treatment. Former gives satisfactory removal with final pH value of 6.9 and eliminates boiler scale difficulties which have always resulted when lime dosage has been increased in effort to increase iron removal. Typhoid death rates, including paratyphoid, in state in 1934 were 2.4 and 3.4 per 100,000, inclusive and exclusive of Baltimore, respectively. Latter rate is lowest ever recorded. Rate for Baltimore was 1.3.—*R. E. Thompson.*